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AFWL-TR-70-30

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C-141A GROUND FLOTATION TEST ON LANDING MAT AND UNSURFACED RUNWAYS CIVIL ENGINEERING SUPPORT

DeLynn R. Hay
Capt USAF

TECHNICAL REPORT NO. AFWL-TR-70-30

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AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
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FOREWORD

This research was performed under Program Element 41118F, Project 476L, and was funded by ASD in Procurement Directive ASD/AFWL 68-8 and 69-1.

Inclusive dates of research were December 1967 through September 1968. The report was submitted 19 February 1970 by the Air Force Weapons Laboratory Project Officer, Capt D. R. Hay (WLCT).

Information in this report is embargoed under the US Export Control Act of 1949, administered by the Department of Commerce. This report may be released by departments or agencies of the US Government to departments or agencies of foreign governments with which the United States has defense treaty commitments, subject to approval of AFWL (WLCT), Kirtland AFB, NM, 87117.

The data for the landing mat runway portion of the program was collected and provided to AFWL by the US Army Engineer Waterways Experiment Station (WES), Corps of Engineers, Vicksburg, Mississippi, under MIPR AFWL 68-12. Mr. C. D. Burns and Mr. R. W. Grau of WES are especially acknowledged for their cooperation and assistance during the runway reconstruction and tests conducted at Dyess AFB, Texas. Support was provided by the 96 Combat Support Group during the tests at Dyess AFB, especially Base Civil Engineering (Mr. C. M. Ferguson) and Base Operations (Mr. M. Chorn and Lt Colonel V. E. Davis). Support for the unsurfaced testing at Harper Lake was provided by the Air Force Flight Test Center at Edwards AFB, California. The assistance of Captain D. D. Currin, Captain D. I. Hanson, and Mr. L. M. Womack (all of WLCT) during the test program and preparation of the report is acknowledged.

This technical report has been reviewed and is approved.

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ABSTRACT

(Distribution Limitation Statement No. 2)

The Air Force Weapons Laboratory, Civil Engineering Division (AFWL/WLCT), provided civil engineering support for the C-141A Ground Flotation Test on a landing mat runway and an unsurfaced runway. The flight tests were conducted by the Lockheed-Georgia Company. The primary objectives of the test program were to determine the capability of the C-141A aircraft to operate from landing mat runways and to demonstrate the capability to operate on an unsurfaced runway. The support provided included soil strength measurements on the runways, elevation profiles on the runways, and evaluation of the effect of the C-141A on the unsurfaced and landing mat runways. The data collected during the test program are presented and discussed. Approximately 370 takeoffs, landings, and taxis were conducted on the landing mat runway without any major operational problems. Fourteen C-141A operations were successfully conducted on an unsurfaced runway with soil strengths ranging from CBR 2 to CBR 20.

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SECTION I

INTRODUCTION

The C-141A must be able to operate in concert with the C-5A to fulfill the mission of the Military Airlift Command. The C-141A was designed to operate only on established, hard surface runways. The C-5A is being procured with a high-flotation landing gear to meet the requirement for sustained operation on support area landing mat and unsurfaced airfields. If the C 141A must restrict its operation to rear area, hard-surfaced airfields, a complex logistics network must be supported to transport C-141A payload to battle areas. This, in turn, imposes severe constraints on the employment of strategic airlift forces to meet contingency requirements. The mission of the strategic airlift force, coupled with the composition of that force into the 1980 time period, dictates a maximum degree of operational compatability between the C-141A and the C-5A aircraft. The deployment concept requires that both these aircraft operate from the same type airfields. Thus, the C-141A must have the capability to operate on support area airfields. The purpose of this test was to determine the capability of the C-141A for operation on landing mat runways and demonstrate a capability on unsurfaced runways. The C-141 Systems Program Office of the Aeronautical Systems Division was responsible for the conduct of the C-141A Ground Flotation Test.

The C-141A Ground Flotation Test consisted of extended flight tests on a landing mat runway and limited flight tests on an unsurfaced soil runway. The landing mat runway phase of the test program was conducted during the period 24 June through 26 August 1968. The unsurfaced soil runway flight tests were conducted on 11 September 1968. The objectives of this test program were as follows:

a. Determine the present capability of the C-141A aircraft to operate from landing mat runways.

b. Determine the amount of C-141A operational improvement on landing mat runways that could be obtained by the use of tire deflation techniques.

c. Determine C-141A operating limitations, if required, when tire deflation devices are used.

d. Develop flight handbook data from which operational decisions can be made on the capability of the C-141A aircraft to operate from specific landing mat runways.

e. Determine the effect of landing mat operations on the fatigue life of the C-141A aircraft.

f. Demonstrate the capability of the C-141A aircraft to operate on an unsurfaced runway.

g. Determine the aircraft dynamic response to the profile of the unsurfaced runway.

The Air Force Weapons Laboratory objectives, in addition to the above, for the unsurfaced tests were to

a. Conduct limited evaluation of certain dust suppressant agents under operational conditions on unsurfaced runways.

b. Collect data during the test program that may be used for partial validation of presently available unsurfaced runway design and evaluation curves.

The landing mat runway was located at Dyess AFB, Texas. The runway was 6000 feet long and 96 feet wide with a 1250-foot long and 60-foot wide taxiway connecting the main Dyess runway and turnaround loops at both ends of the runway. The Dyess AFB runway is constructed with XM18B, XM18C, XM19, and AM2 landing mat over a heavy clay subgrade. The bare soil runway used for the C-141A flight tests was located at Harper Lake, California. Harper Lake is a playa located approximately 35 miles east-northeast of Edwards AFB in the western Mojave Desert in California. A runway 6300 feet long was located and used for the flight tests. The surface soils of Harper Lake are predominantly clayey silts. Most of the runway area had California Bearing Ratios (CBR) ranging from 10 to 20, although there were limited areas on the runway with CBRs ranging from 1 to 9.

The flight tests were conducted by Lockheed-Georgia Company under Contract F33657-68-C-0347 with the C-141 Systems Program Office of the Aeronautical Systems Division. The Air Force Weapons Laboratory (AFWL), Civil Engineering Division (WLCT), provided civil engineering support for the test. The civil engineering support for the landing mat phase was accomplished by the US Army Engineers Waterways Experiment Station under the supervision of AFWL. The

support provided included soil strength measurements on the runways, elevation profiles on the runways, and evaluation of the effect of the C-141A on the unsurfaced and landing mat runways.

This report presents that information related to the civil engineering support provided for the C-141A Ground Flotation Test. A report describing in detail the aircraft performance and structural response of the aircraft has been prepared by Lockheed-Georgia Company (Refs. 1, 2). The information for the landing mat portion of this report was provided by test site visits of the AFWL project officer and discussions and correspondence with the Waterways Experiment Station.

SECTION II

TEST CONDUCT

1. LANDING MAT

a. Test Site

(1) Dyess AFB Landing Mat Runway

A landing mat runway was constructed at Dyess AFB, Texas, in the last half of 1966. The runway was constructed for the Tri-Service Operational Test of Landing Mats to determine the suitability of various types of landing mats for sustained tactical operations (Refs. 3, 4). Flight tests for the Tri-Service program were conducted between December 1966 and May 1967. The landing mat was to have been removed and the time and effort required for removing, cleaning, and rebundling the mats for reuse determined. The removal phase of the program was cancelled so that the runway could be used for the C-141A Ground Flotation Test.

The test aircraft was towed on the landing mat runway on 9 December 1967. This towing indicated that there was a considerable amount of the runway subgrade that would not support C-141 operations. Strength measurements made at three locations on the runway had not indicated a weak subgrade; however, towing of the aircraft indicated that at least 3200 feet of the runway had low strengths. In the soft subgrade areas, the mat deflected 2 to 3 inches under the aircraft and a 4- to 6-inch high bow wave was formed immediately ahead of the main landing gear wheels.

In discussions between Air Force and Army representatives, it was decided to completely reconstruct the landing mat runway. Funds for the reconstruction were provided by AFWL and the Army Materiel Command (AMC). The funds provided by AMC were used for the purchase and evaluation of a number of dust suppressant agents. The reconstruction of the runway was accomplished by the US Army 63rd Engineer Battalion, under the engineering supervision of the Waterways Experiment Station (WES). AFWL (WLCT) provided Air Force field surveillance of the reconstruction. A report was published by the Waterways Experiment Station on the runway reconstruction and evaluation of the dust suppressants (Ref. 5).

All the landing mat panels, membranes, and accessory items were removed from the runway, taxiway, and turnaround loops and stored for reuse. In general, the subgrade beneath the lightweight membranes was unstable and wet due to open joints, tears, and small pinholes in the membrane. The subgrade soil in the wet areas was either reprocessed or removed and replaced with a drier material. The subgrade of the runway was reconstructed to provide a 2.5 percent crown. The reconstructed subgrade was waterproofed by spraying asphalt emulsion on the graded subgrade, placing polypropylene cloth over the asphalt emulsion, spraying the surface of the polypropylene with a light application of asphalt emulsion, and then overlaying the polypropylene with the recovered membrane used in the original construction. The landing mat was relaid over the waterproofing material. After placing 40 runs* of XM18 in the normal brick-type laying pattern, the remaining XM18 and AM2 was laid in a 1-foot staggered end-joint pattern with a half-panel placed at the centerline of the runway. The laying patterns are shown in figure 1. A number of different dust suppressants were applied on the runway edges and overruns. The layout of dust suppressants and waterproofing materials is shown in figure 2.

The test facility consisted of a runway, 6000 feet long and 96 feet wide; a taxiway 1252 feet long and 60 feet wide, connecting with the main Dyess runway; and a turnaround loop at both ends of the runway.

Four types of landing mat (XM18B, XM18C, XM19, and AM2) were used to surface the runway; the location of the various mats is shown in figure 3. A description of each type of mat is provided in the following paragraphs.

The XM19 mat is an expanded aluminum foil honeycomb core bonded to 1/16-inch cover plates. Edge connectors are welded to the top and bottom sheets and bonded to the core material. The core is formed from 5056 aluminum alloy foil 0.0027 inch thick and is formed into 1/8-inch hexagons. The nominal dimensions of the panels are 4 feet 2-1/4 inches by 4 feet 1-1/2 inches by 1 foot 1/2 inch. The locking edges of the panels are locked together with a locking bar. The top surface of the panels is coated with an anti-skid material. The XM19 landing mat panel is shown in figure 4.

*A run is a strip of landing mat equal to one panel width and extending transversely across the entire runway.

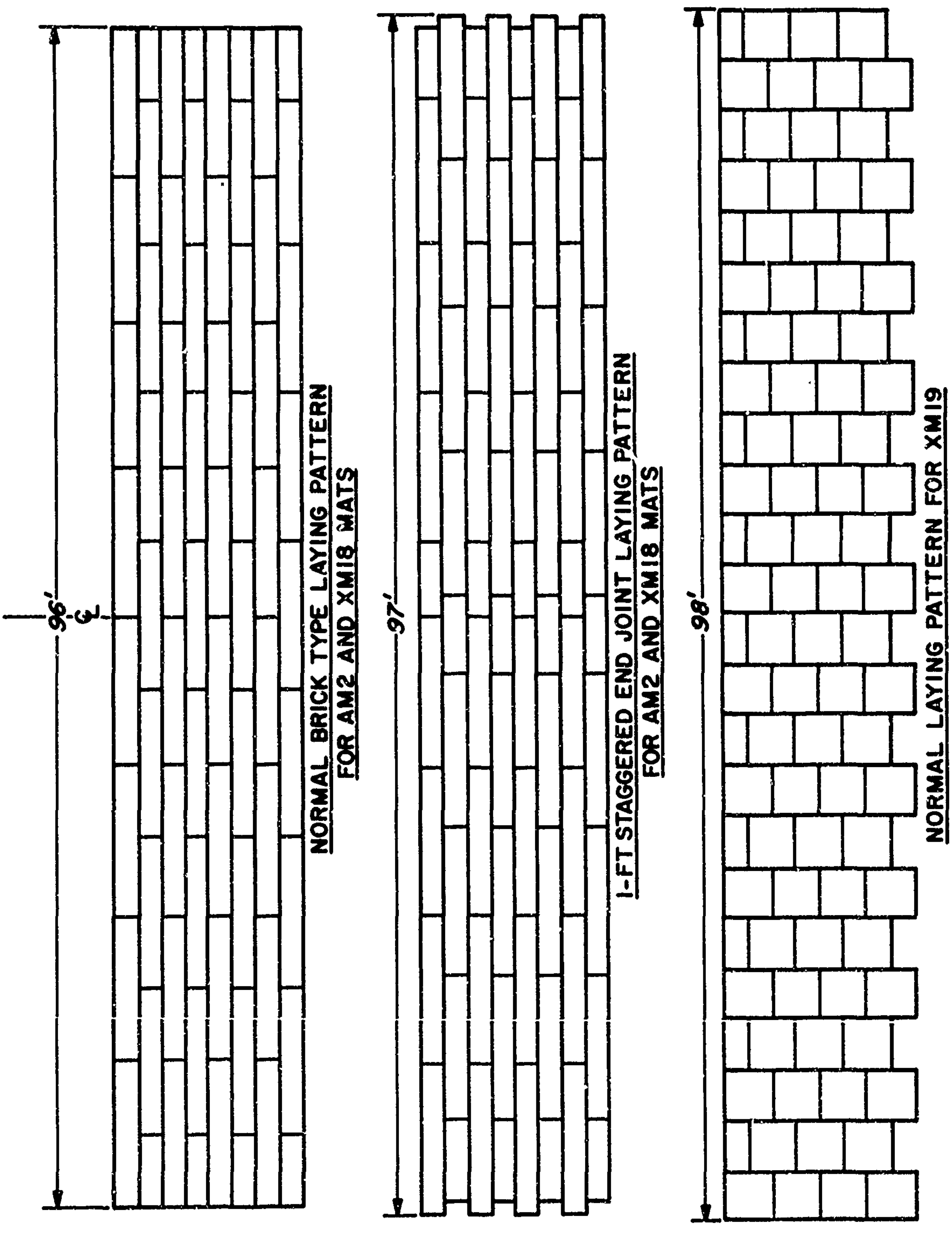
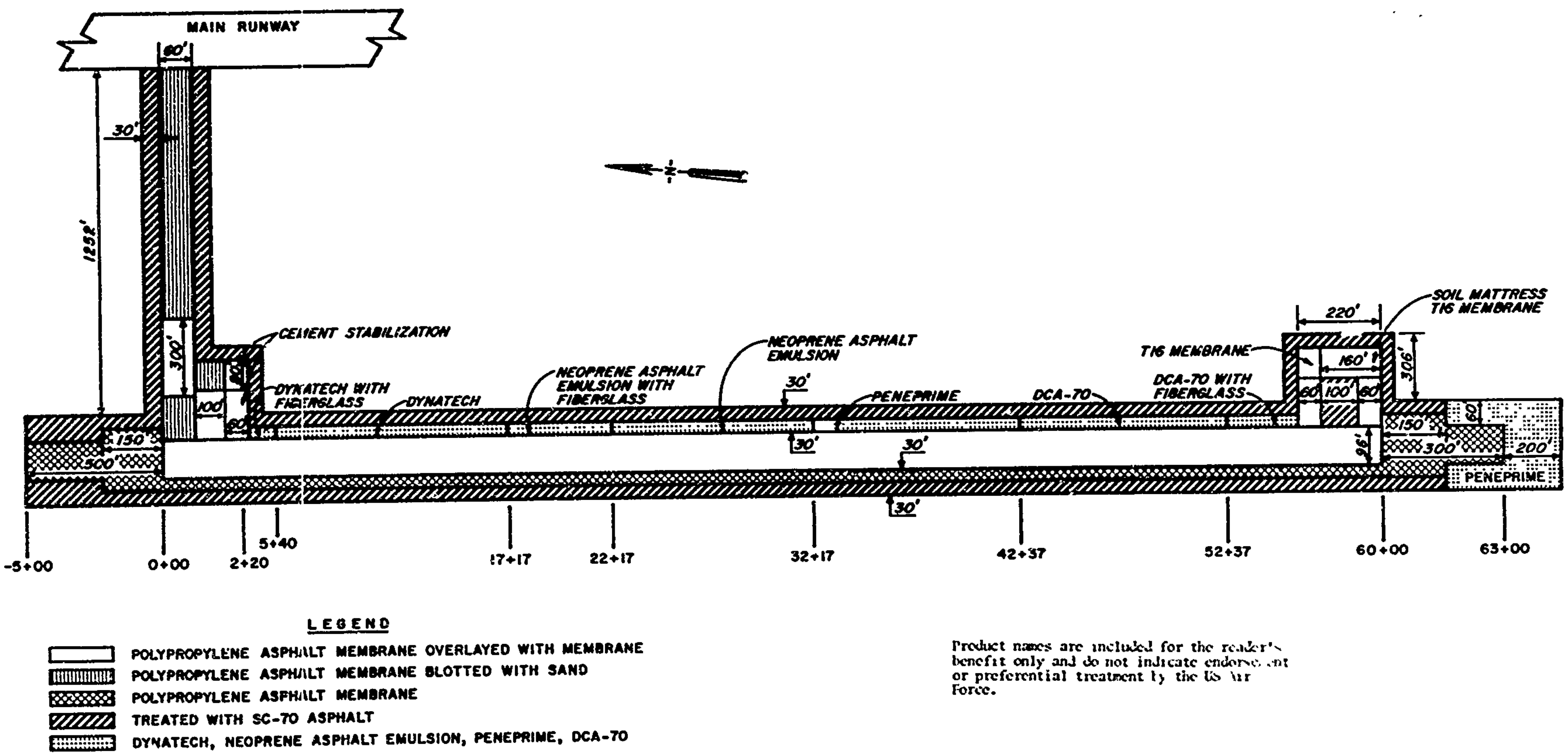


Figure 1. Laying Patterns Used on Landing Mat Runway, Dyess AFB



Product names are included for the reader's benefit only and do not indicate endorsement or preferential treatment by the US Air Force.

Figure 2. Layout of Waterproofing and Dust Proofing Plan for Landing Mat Runway, Dyess AFB

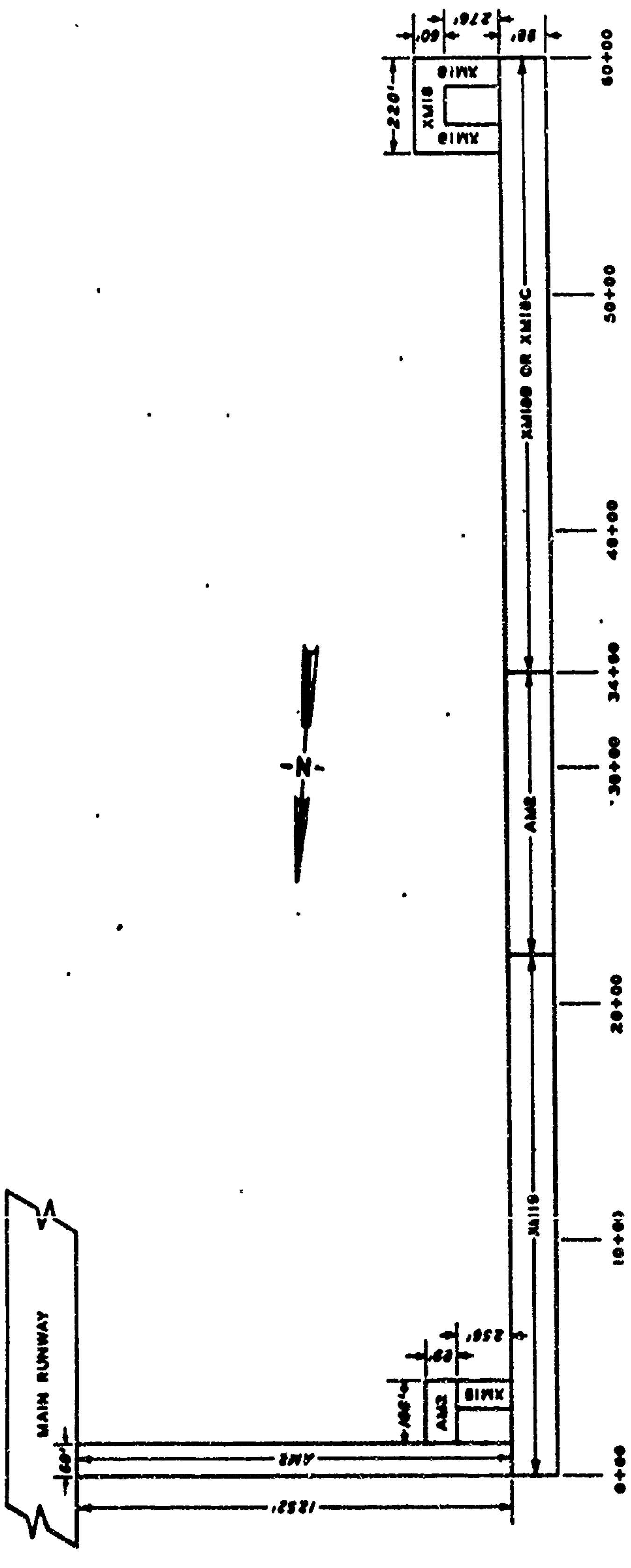


Figure 3. Layout of Mat Placement for Landing Mat Runway, Dyess AFB

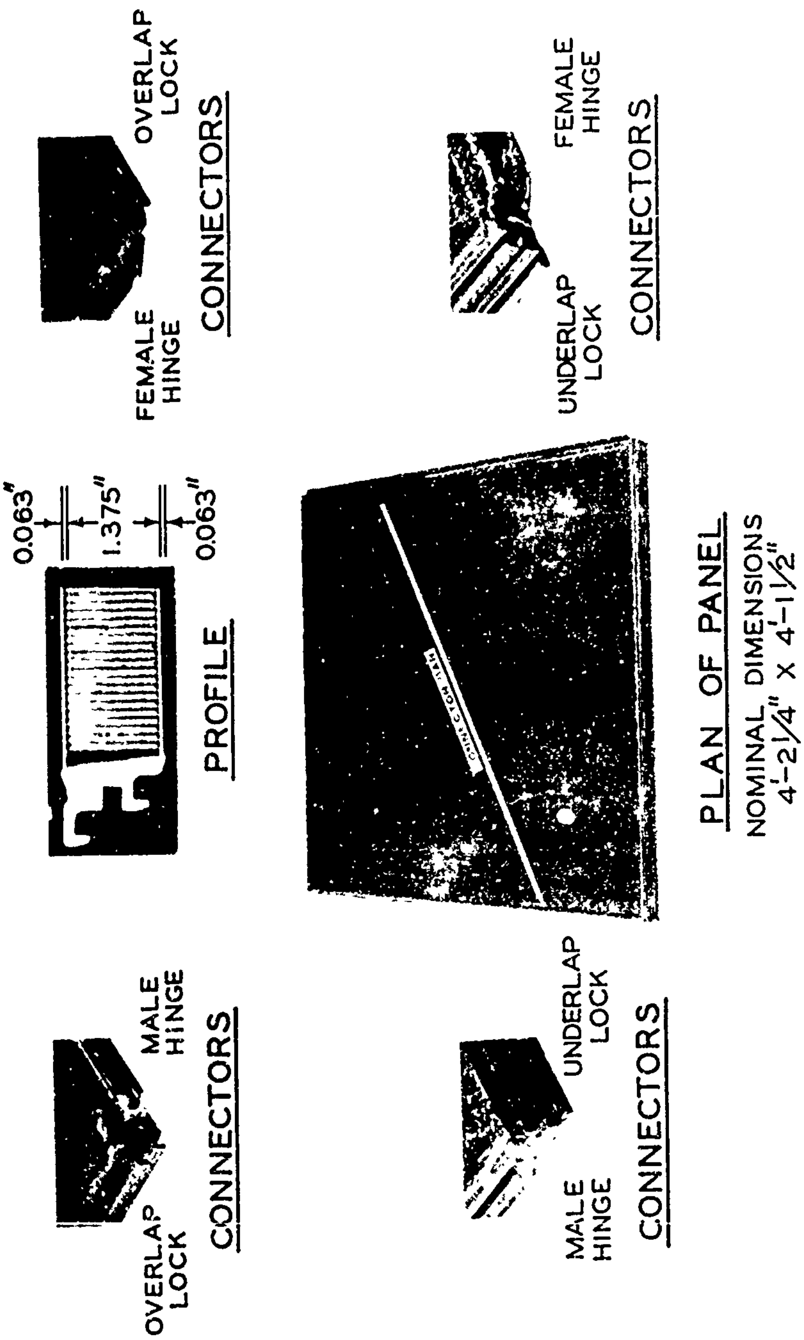


Figure 4. Airplane Landing Mat, Aluminum, Sandwich Type XM19

The XM18B and XM18C landing mat panels are a one-piece hollow extrusion approximately 2 feet wide and 12 feet long, fabricated from 6061 and 7005, respectively, aluminum alloy. Only a small quantity of the XM18C was produced. The panels are locked along the sides by a hinge type connector that is a part of the panel extrusion. The end connectors are an extruded connector welded to the panel with an overlap and underlap section and a slot for a locking bar. The top surface is coated with an anti-skid material. The XM18 mat is shown in figure 5.

The AM2 mat used for the Dyess runway was constructed of two extruded aluminum sections (each 1 foot by 12 feet) welded together to form a panel 2 feet by 12 feet by 1-1/2 inches. The extrusions are formed from 6061-T6 aluminum alloy. (The AM2 mat can also be fabricated with a one- or three-piece extrusion.) The AM2 mat is similar in appearance to the XM18 mat.

(2) Runway Profiles

Prior to relaying the landing mat, profile measurements were taken on the runway subgrade at 2-foot intervals horizontally along lines 10.6 feet left and right of the runway centerline. The outside of the C-141 main landing gear is approximately 10.6 feet from the runway centerline when the aircraft is centered on the centerline. Cross-section measurements were also made on the runway. Unloaded profile measurements at 2-foot horizontal intervals were taken on the landing mat 10.6 feet right and left of the runway centerline between stations 2 + 00 to 4 + 00, 29 + 00 to 31 + 00, and 56 + 00 to 58 + 00; (runway stationing is shown in figures 2 and 3). A loaded profile was taken with an aircraft gross weight of 257,500 pounds between stations 2 + 00 and 58 + 00; the measurements were taken next to the main landing gear aft wheel and with the nose landing gear on the runway centerline. The measurements were taken at the center of the 2-foot landing mats and at the center and edge of the 4-foot landing mats. The profile measurements were made as the aircraft was towed down the runway. Loaded profile measurements at an aircraft gross weight of 1900,000 pounds were made between stations 2 + 00 to 4 + 00, 29 + 00 to 31 + 00, and 56 + 00 to 58 + 00. There were no significant differences between the profiles measured at aircraft gross weights of 190,000 pounds and 257,500 pounds. Approximately midway in the flight testing, unloaded profile measurements were made at the same location as those made prior to flight tests with no significant differences. A loaded profile at an aircraft gross weight of 257,500 pounds was taken at the conclusion of all flight tests. This profile showed no significant changes in the loaded landing mat profile caused

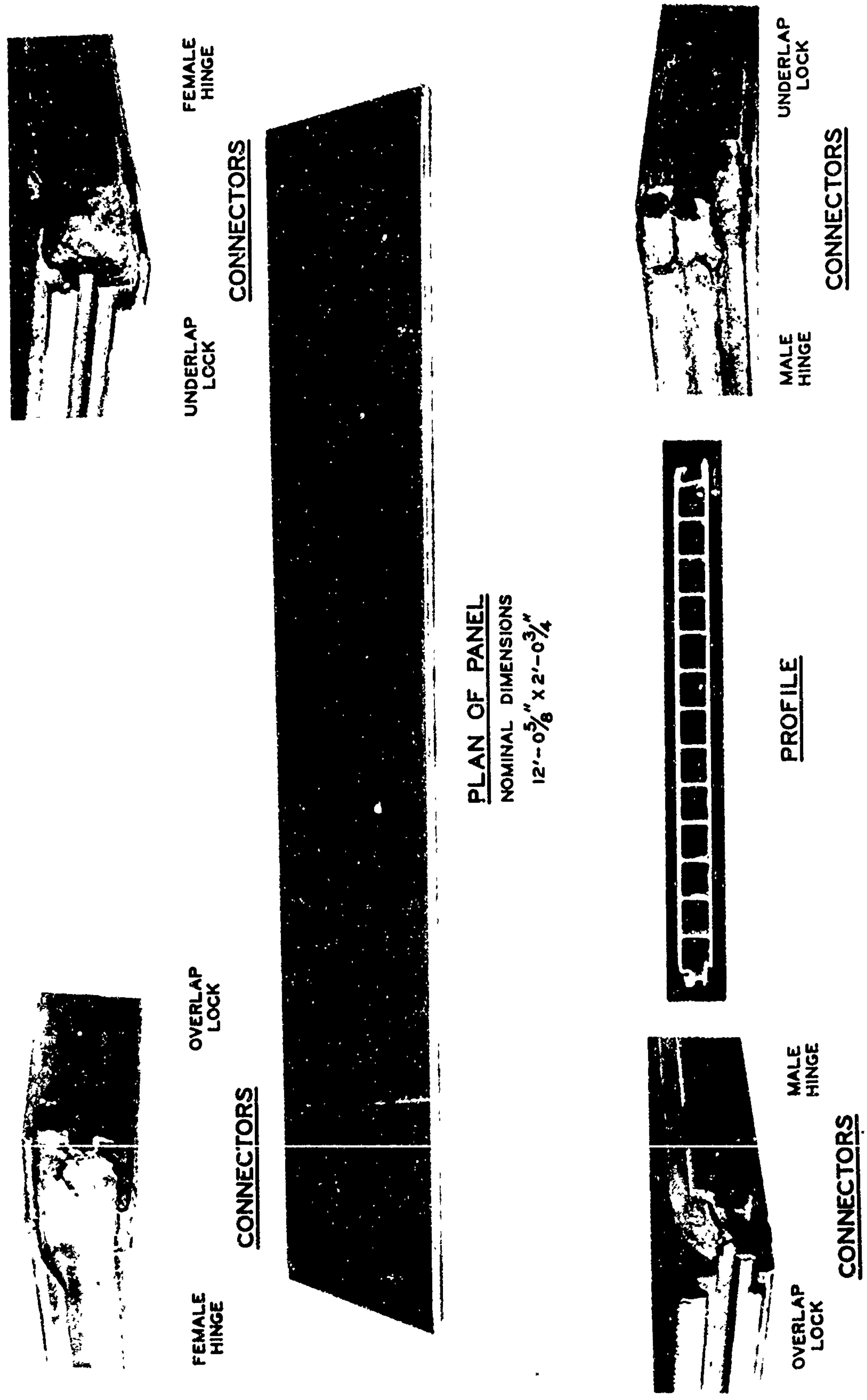


Figure 5. Airplane Landing Mat, Aluminum, Type XM18

by the C-141A flight operations. A 2-foot horizontal interval profile was also made of the center line of the main Dyess AFB runway. The volume of the profile data precludes including it in this report; the data is available on request from AFWL (WLCT-A), Kirtland AFB, NM, 87117.

(3) Runway Subgrade

The subgrade soil of the landing mat runway consists primarily of a heavy clay (CH); classification data is shown in figure 6. Prior to laying the landing mat, field in-place subgrade water content, density, and California Bearing Ratio (CBR) measurements were made at a number of locations on the runway. Replacement landing mat panels that allow the removal of only one panel were placed at the locations of the soil tests. Following the flight tests, the replacement panels were removed and the soil moisture, density, and strength measurements were repeated. A summary of the soil measurements conducted following the reconstruction of the subgrade and at the conclusion of the flight tests is shown in table I. The average subgrade soil strength in the top 6 inches was approximately a CBR 12 before the flight tests and a CBR 20 at the conclusion of the flight operations. There was little change in soil strength below the 6-inch depth.

b. Flight Operations

The flight tests were conducted by Lockheed-Georgia Company using a standard C-141A (AF61-2777) modified to meet the requirements of the test program. The C-141A has a twin-tandem main landing gear system with the geometry as shown in figure 7. The tire contact area is approximately 208 square inches.

The aircraft was instrumented to obtain structural loads data and performance data. A complete description of the aircraft instrumentation and details and results of the flight test program can be found in reference 1. The results of the aircraft dynamic analysis conducted for this program can be found in reference 2.

Aircraft operations were conducted at Dyess AFB between 3 July and 26 August 1968. Approximately 95 takeoffs, 85 landings, and 190 taxis were performed on the landing mat runway. Pivot turns, braking taxi turns, braking stops, and determinations of the runway coefficient of friction were performed throughout the test program. Straight taxi tests were conducted at gross weights of 190,000, 220,000, 257,500, and 300,000 pounds with normally inflated tires (185 psig main tire pressure), at gross weights of 190,000 and 257,500

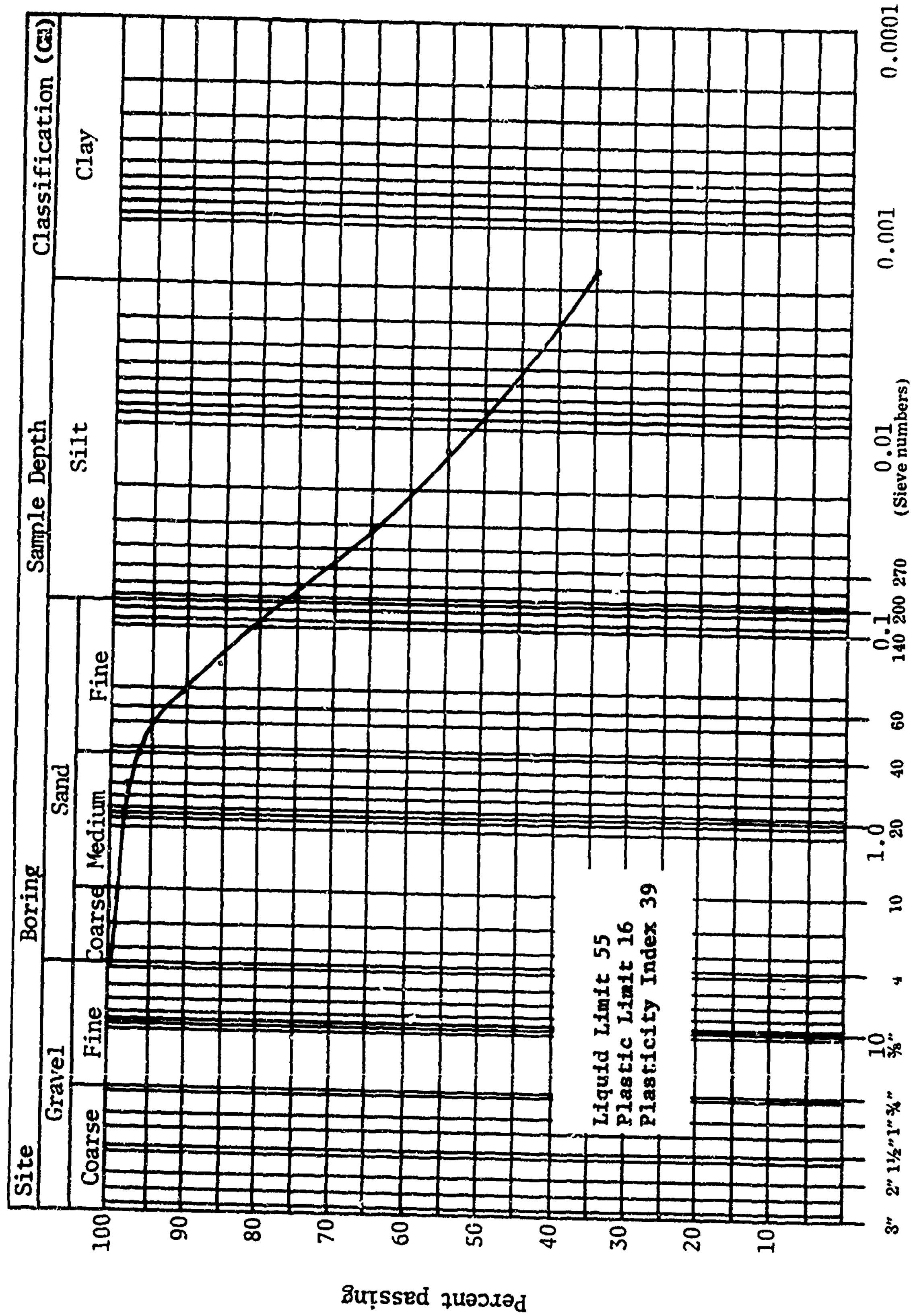


Figure 6. Soil Classification Data, Subgrade Landing Mat Runway, Dyess AFB

Table I

SUMMARY OF CBR, WATER CONTENT, AND DRY DENSITY DATA, LANDING MAT RUNWAY, DYESS AFB

Location	Type Mat	Subgrade Material	Station	Distance from ℄ ft	Depth in.	Prior to Mat Placement CBR	Prior to Mat Placement Water Content %	Prior to Mat Placement Dry Density pcf	After Aircraft Operations CBR	After Aircraft Operations Water Content %	After Aircraft Operations Dry Density pcf	Remarks
Runway	XM19	Heavy clay	[illegible]+50	12 left	0	16	12.1	106.8	21	10.3	[illegible]	
					6	14	12.5	105.9	17	9.5	[illegible]	
					12	[illegible]	[illegible]	99.2	16	4.8	--	
			7+50	12 right	0	11	10.6	95.5	3	19.4	[illegible]	No Herculite membrane overlaying the polypropylene asphalt membrane
					6	15	12.0	95.1	6	19.9	105.1	
					12	10	11.3	97.3	11	8.0	111.0	
					18	8	16.9	93.5	9	19.6	105.0	
					24	5	17.5	104.4	--	--	--	
			12+50	12 left	0	9	10.4	109.7	45	8.2	103.1	
					6	9	17.8	101.2	23	9.0	98.8	
					12	9	19.0	102.8	11	17.3	100.4	
					18	10	9.6	109.7	8	22.4	101.2	
					24	11	17.0	106.7	--	--	--	
			17+50	12 right	0	17	13.5	96.7	30	9.4	96.1	
					6	11	16.5	98.8	22	10.4	96.[illegible]	
					12	15	15.8	99.4	10	13.9	106.7	
Runway	AM2	Heavy clay	22+50	12 left	0	13	9.0	109.2	14	11.2	93.[illegible]	
					6	11	16.2	102.1	16	18.2	104.6	
					12	8	16.6	99.5	11	17.4	107.5	
			27+50	12 right	0	11	17.6	98.8	36	11.6	102.2	
					6	11	18.3	99.8	11	12.1	93.9	
					12	10	18.1	106.1	9	16.8	85.7	
					18	8	20.8	100.3	12	19.7	94.5	
					24	3	20.4	95.9	8	17.2	97.6	
			32+50	12 left	0	18	13.7	103.0	17	12.5	104.0	
					6	23	14.5	111.5	9	19.0	84.4	
					12	15	16.2	104.4	18	15.7	105.0	
					18	13	15.4	103.7	11	17.2	100.2	
					24	12	12.8	104.0	7	[illegible]	[illegible]	
Runway	XM18B or XM18C	Heavy clay	37+50	12 right	0	13	13.9	100.7	--	--	--	No replacement plank
					6	11	18.4	104.4	--	--	--	
					12	9	18.3	106.8	--	--	--	
			42+50	12 left	0	13	16.6	104.1	9	16.1	100.8	
					6	13	18.7	103.9	9	19.4	98.4	
					12	16	17.7	105.8	10	19.0	97.1	
			47+50	12 right	0	13	16.2	105.1	22	10.9	110.4	
					6	13	20.1	103.9	12	13.9	106.2	
					12	11	18.4	103.1	8	[illegible]	105.1	
					18	9	17.8	100.6	8	19.1	101.7	
					24	8	20.7	102.0	[illegible]	11.7	106.9	
			52+50	12 left	0	12	16.3	106.4	28	7.9	102.6	
					6	11	16.0	100.3	22	10.0	98.4	
					12	11	16.9	105.9	24	10.8	107.1	
					18	10	18.5	105.2	10	16.7	106.4	
					24	10	18.4	104.7	12	15.6	98.8	
			57+50	12 right	0	5	15.4	97.1	[illegible]	[illegible]	105.9	
					6	23	11.8	104.7	13	17.7	100.4	
					12	25	12.6	104.7	9	16.4	105.3	
Taxiway	AM2	Heavy clay	6+00	10 right	0	12	14.8	98.0	[illegible]	13.3	99.2	Polypropylene asphalt membrane blotted with sand
					6	11	12.0	103.4	15	13.7	98.9	
					12	18	15.7	100.9	14	11.1	101.8	
					18	[illegible]	10.2	96.4	10	13.8	[illegible]	
					24		18.4	100.6	7	21.1	101.6	
			10+00	10 left	0	13	18.4	94.9	21	10.0	102.4	Polypropylene asphalt membrane blotted with sand
					6	16	17.5	102.6	13	11.8	101.0	
					12	9	9.2	105.3	9	14.1	104.2	
Mattress section	XM18B or XM18C	Heavy clay	1+10	Center	0	12	12.5	102.0	37	11.7	103.6	
					6	8	10.5	98.8	15	12.3	102.8	
					12	8	10.9	108.8	8	13.7	91.1	
North loop south leg	XM19	Soil cement	1+00	Center	0	38	10.5	114.0	--	--	--	No replacement plank
			2+20	Center	0	47	10.1	122.0	42	16.1	122.2	No waterproofing material
North loop east leg	AM2	Soil cement	1+20	Center	0	58	5.2	136.0	--	--	--	No replacement plank

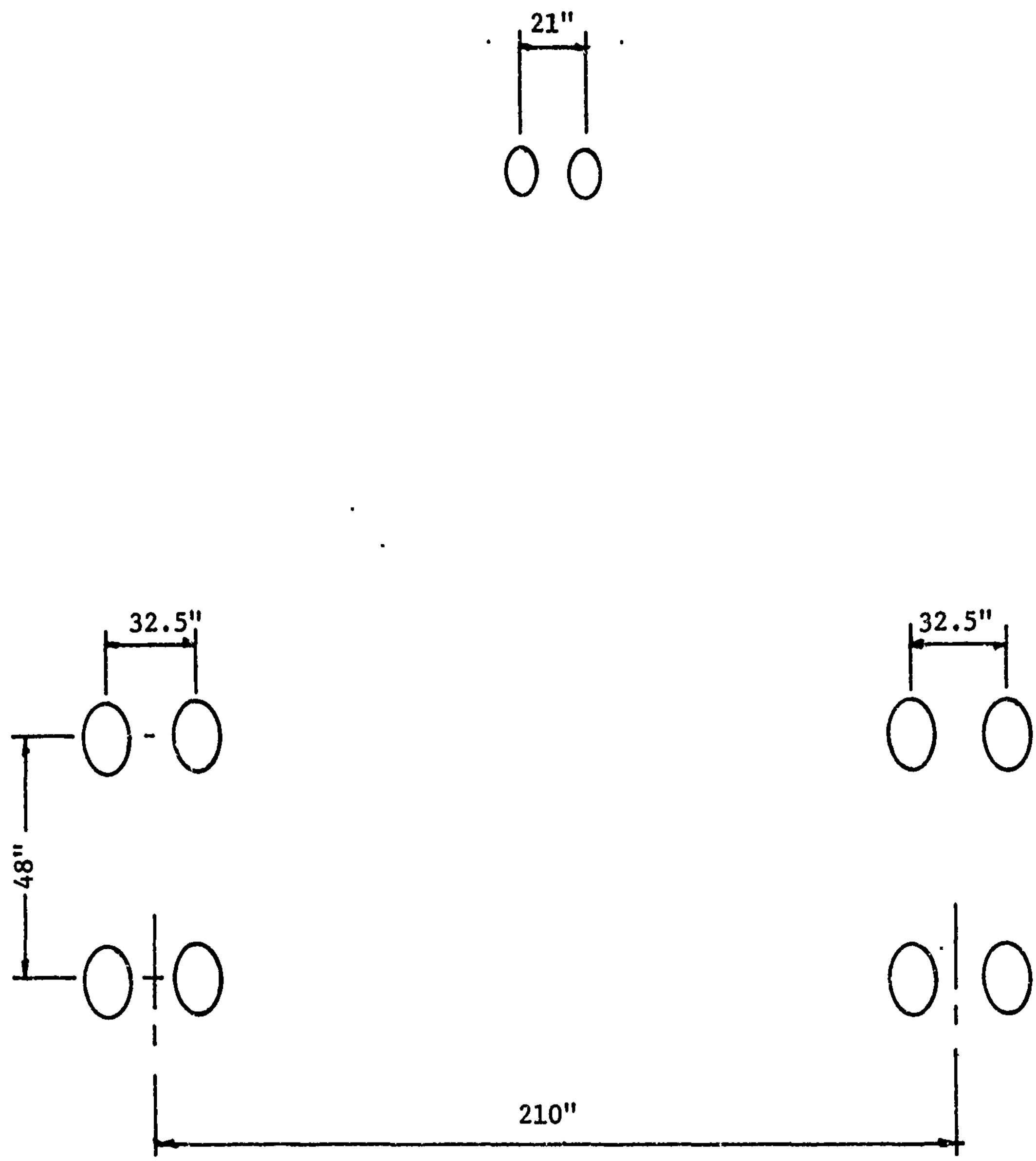


Figure 7. C-141A Landing Gear Layout

pounds with the pressure in the main tires reduced to 140 psig, at gross weights of 190,000 and 220,000 pounds with the pressure reduced in the main tires to 100 psig, and at 257,500 pounds with the main tire pressure reduced to produce 40 percent deflection for the inboard main tires. The taxis were conducted in both directions on the runway and at speeds of 20 and 40 knots. Landings and takeoffs were performed at aircraft gross weights of 190,000, 220,000, and 257,500 pounds with main tire pressure of 185 psig, at 190,000 and 220,000 pounds with 100 psig main tire pressure, and at 257,500 pounds with the main tire pressure reduced to produce 40 percent deflection on the inboard tires. The landings were conducted with sink rates of 2 to 5 ft/sec and 5 to 8 ft/sec. Four takeoffs and landings were conducted at night with an aircraft gross weight of 257,500 pounds and normal tire inflation pressure to qualitatively evaluate night operations from the landing mat runway. The lighting was provided by the 516th Tactical Airlift Wing (10th Aerial Port Squadron) and placed in accordance with tactical assault runway procedures. A series of takeoffs, landings, and taxis were conducted on wet mats at a gross weight of 220,000 pounds and with a main tire pressure of 100 psig. The wet mat tests were conducted during a rain shower; the desired number of wet mat tests could not be completed because the runway could not be sufficiently wetted by artificial methods. Taxis, takeoffs, and landings were conducted on the main Dyess AFB runway at aircraft gross weights of 190,000 and 316,000 pounds with main tire pressures of 100 psig and 170 psig (40 percent tire deflection), respectively. The main runway operations were conducted to evaluate the effects on airplane performance and structural loading as the result of operating on a normal hard surface with deflated tires. A water ballast system was installed in the cargo area of the aircraft to vary the cargo weight and center of gravity location.

2. UNSURFACED TESTS

a. Test Site

Harper Lake, California, was selected as the test site on the basis of a survey made in early 1968 by the Air Force Weapons Laboratory to select a site for C-5A support area airfield flight tests. Several playas in Southern California were investigated during this survey. Although a number of unsurfaced runways exist in the United States, Harper Lake was selected for the following reasons: the desired soil strengths were available and there was a range of soil strengths; there was adequate area for locating a runway; little or no construction was required; flight test support was available at Edwards

AFB, California; and previous flight tests had shown that Harper Lake was an ideal location for such testing. Figure 8 is a map showing the layout of Harper Lake and the general location of the runway used.

The Air Force Systems Command Civil Engineering Site Selection Team (PRIME BEEF Number 76, provided by Hq USAF/AFOCEC) was at Harper Lake from mid-July to mid-August to select and lay out the unsurfaced runway. A 1000-foot grid was laid out on the lake bed and at the grid points CBR soil strength, soil moisture, and soil density measurements were made at the soil surface and at 6- and 12-inch depths. Measurements were also made at the 24-inch depth for certain selected grid points. A rain on 6 August 1968 changed the soil strengths measured prior to that date. A strength contour map, based on CBRs measured after the rain, is shown in figure 9. This map indicates the variation of soil strength that existed at Harper Lake. Harper Lake is one of the more uniform lakes with respect to soil strength, so even greater variations could be expected at other playas. Small areas where the strengths were low are not shown. Based on CBRs made following the rain, a runway 8000 feet long and 200 feet wide with an average CBR of 14 was laid out by the PRIME BEEF team (shown in figure 8). However, another rain 3 days before the scheduled test date of 29 August lowered the soil strengths below those necessary for aircraft operations, resulting in test delay.

AFWL returned to Harper Lake on 8 September and the runway previously located was still too weak to support aircraft operations. A new runway 6300 feet long was located and used for the flight tests (identified as AFWL in figure 8). An airfield cone penetrometer was used to obtain an indication of soil strengths when the new runway was located. On 10 September CBR measurements were made at stations 10 + 00, 30 + 00, 40 + 00, and 50 + 00. Figure 10 shows a CBR test being conducted. On 11 September, following the flight tests, additional CBR tests were made at stations 2 + 00 and 43 + 00. The results of the CBR measurements are shown in table II.

The surface soils of Harper Lake are predominantly clayey silts. A typical soil grain size curve is shown in figure 11. The soil surface of the runway could be divided into two general areas. The first of these surface types had a hard, dry crust and the surface was cracked to form polygons; this type of surface is shown in figure 12. The CBRs in these areas ranged from 10 to 20. The second surface type had a soft, moist surface crust; this type of surface will be seen in figure 13 which shows rutting. There were also varying

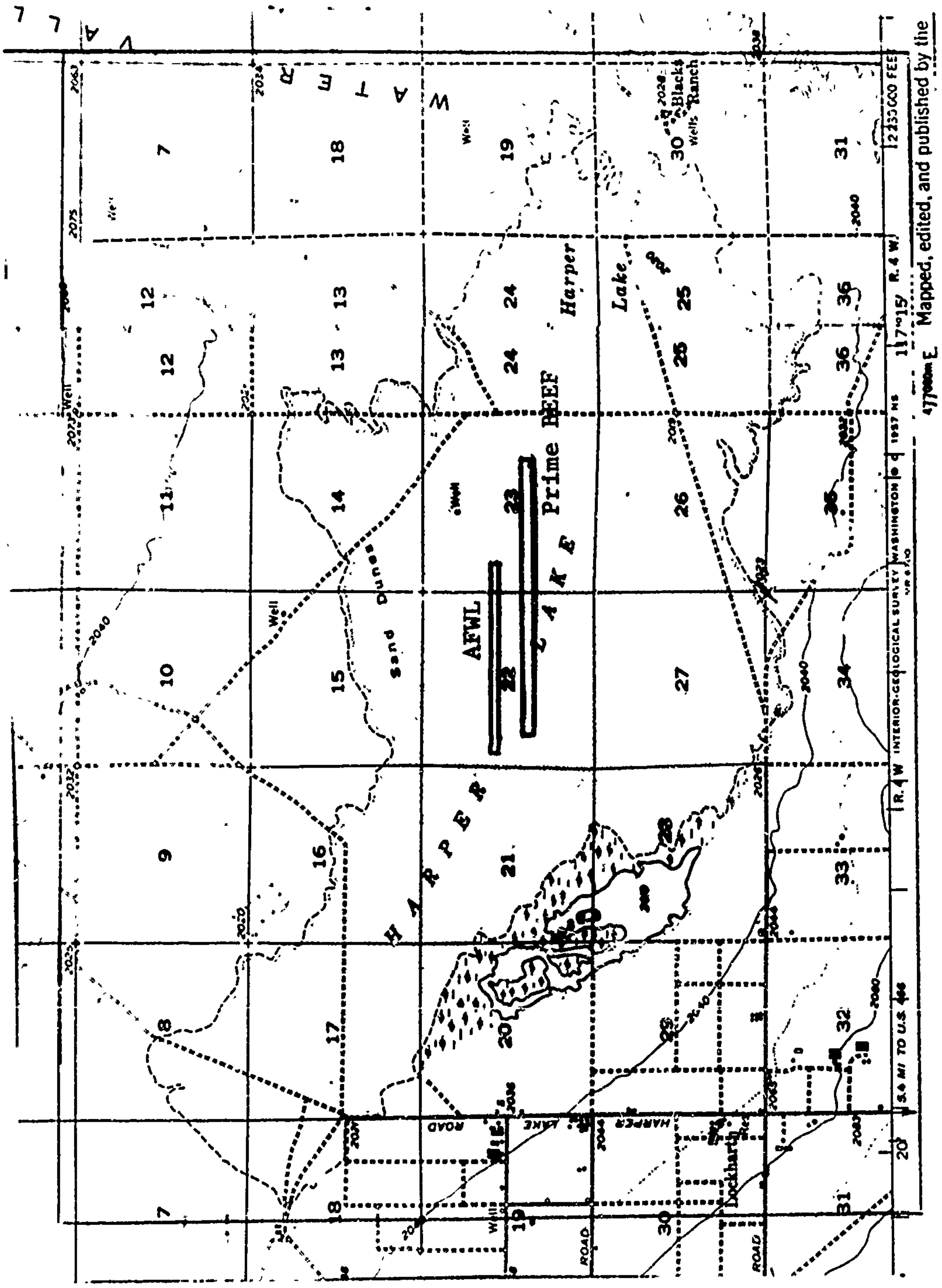


Figure 8. Harper Lake Layout

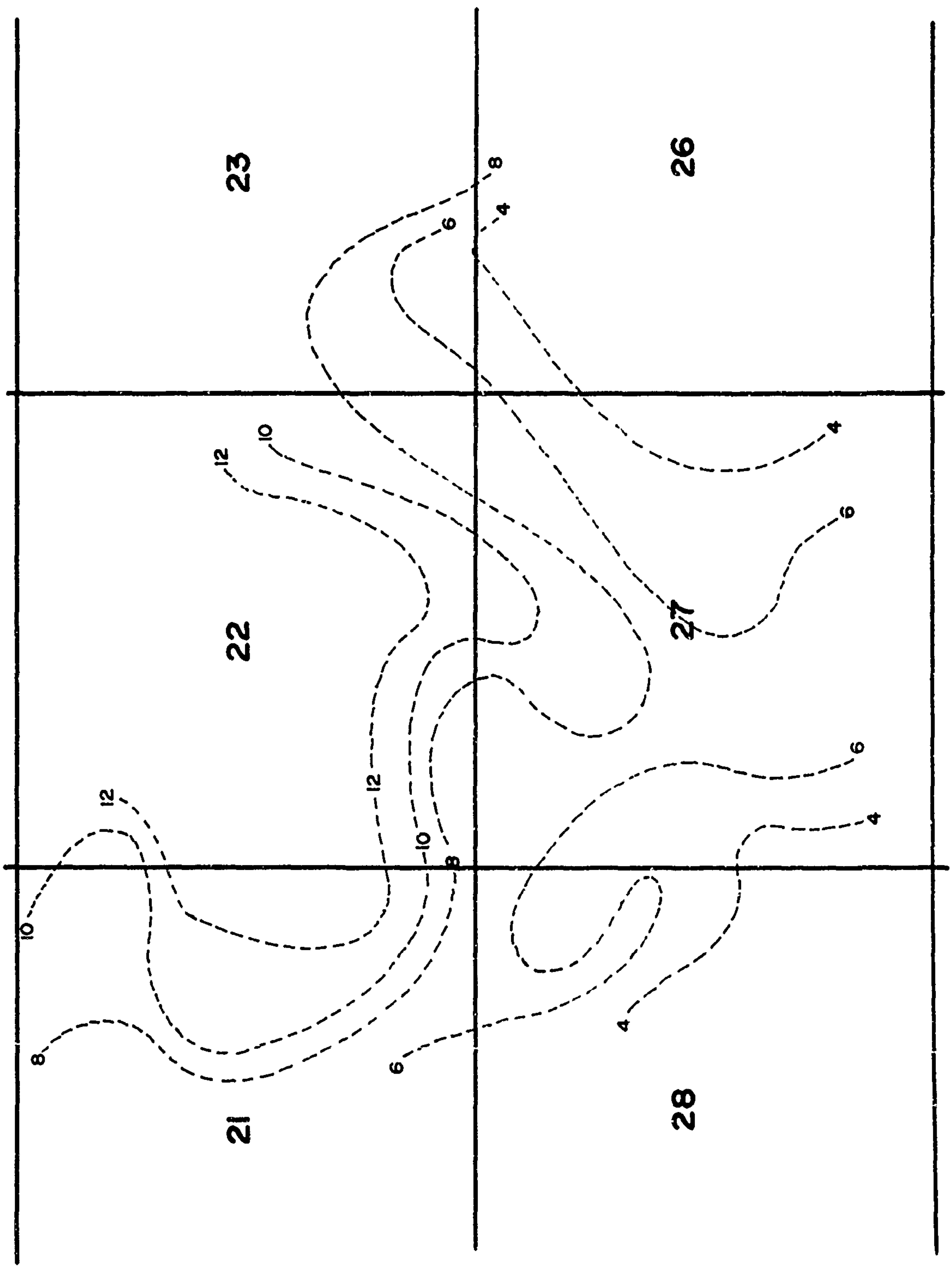


Figure 9. Soil Strength (CBR) Contours, Harper Lake, August 1968

Figure 10. California Bearing Ratio (CBR) Field Soil Strength Test

Table II

CBR MEASUREMENTS, C-141A BARE SOIL RUNWAY, HARPER LAKE

10-11 Sep 68

Runway Station	CBR Surface	CBR 6 inches	CBR 12 inches
2 + 00 30 feet north of centerline	3	9	
10 + 00 100 feet south of centerline	11	12	10
30 + 00 50 feet south of centerline	19	12	13
40 + 00 120 feet north of centerline	1	3	
43 + 00 50 feet north of centerline	2	6	
50 + 00 100 feet south of centerline	20	12	12

Station 0 + 00 was considered to be the east end of the runway.

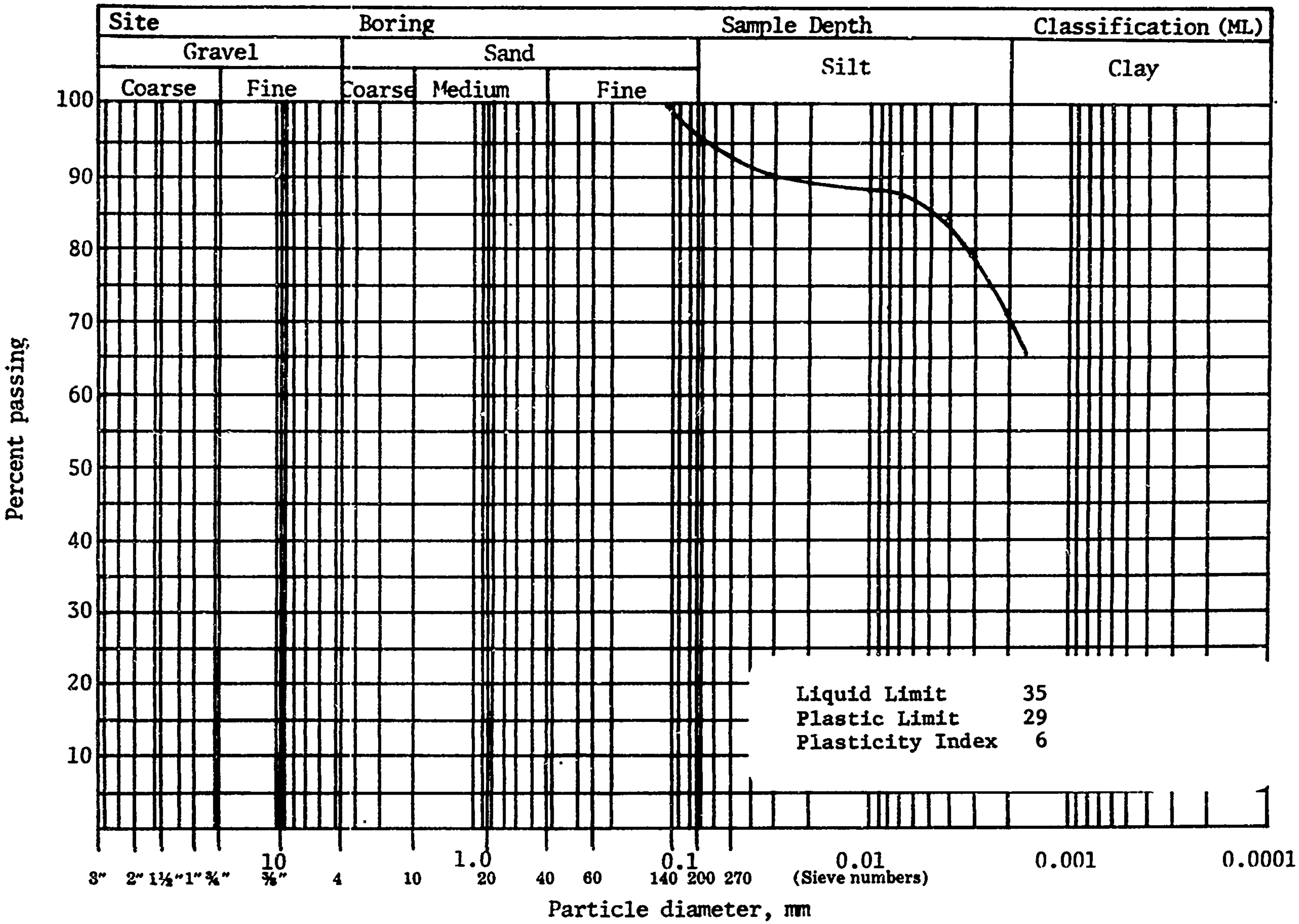


Figure 11. Typical Soil Classification Data, Harper Lake

Figure 12. Hard, Dry Surface Crust, Harper Lake

Figure 13. C-141A Main Landing Gear Rut in Soft Area of Unsurfaced Runway

degrees of a saline crust in these areas. The CBR in these areas ranged from 1 to 9. In figure 14, the approximate locations of the soft areas and significant surface roughness in relation to the runway centerline are shown.

b. Dust Suppressants

One of the problems associated with unsurfaced runway aircraft operations is the dust caused by propeller wash and jet blast. The dust can cause serious visibility problems if it does not dissipate. Foreign objects, small stones and soil particles may also cause increased maintenance as well as serious damage to engines if ingested. To gain additional information on these problems, nine small test sections of commonly available dust suppressants were placed on the test runway. The dust suppressants included a cutback asphalt (MC-70), jet fuel (JP-4), asphalt emulsion (SS-2), and Coherex, a proprietary product of the Golden Bear Oil Company.* The dilutions, rates, and areas of application are shown in table III and the test section layout is shown in figure 15. The dilutions and application rates were selected based on the attempt to get varying degrees of penetration of the materials into the soil. Previous studies have shown that in order to provide adequate protection the asphalt type dust suppressants must penetrate the soil surface. The test sections in place on the runway are shown in figure 16. At the same time the dust suppressants were applied, an 8-foot wide strip of asphalt emulsion was placed on the lake bed to mark the runway centerline and thresholds. The centerline can be seen in figure 16 between the two sets of test sections.

c. Flight Operations

The flight tests were conducted by Lockheed-Georgia Company using the same aircraft used for the landing mat flight tests. The instrumentation was the same as that used for the landing mat test program except for cameras and touchdown wands. Figure 17 shows the aircraft during one of the taxi runs. The aircraft was operated with a tire inflation pressure of 125 pounds psi for the unsurfaced flight tests. The nominal gross weight of the aircraft was 257,500 pounds. The first operation was a touch-and-go landing. This was followed by a landing and a 20-knot taxi in both directions on the runway. Following takeoff and landing, 40-knot taxis were conducted in both directions.

*Company names are included for the reader's benefit only and do not indicate endorsement or preferential treatment by the US Air Force.

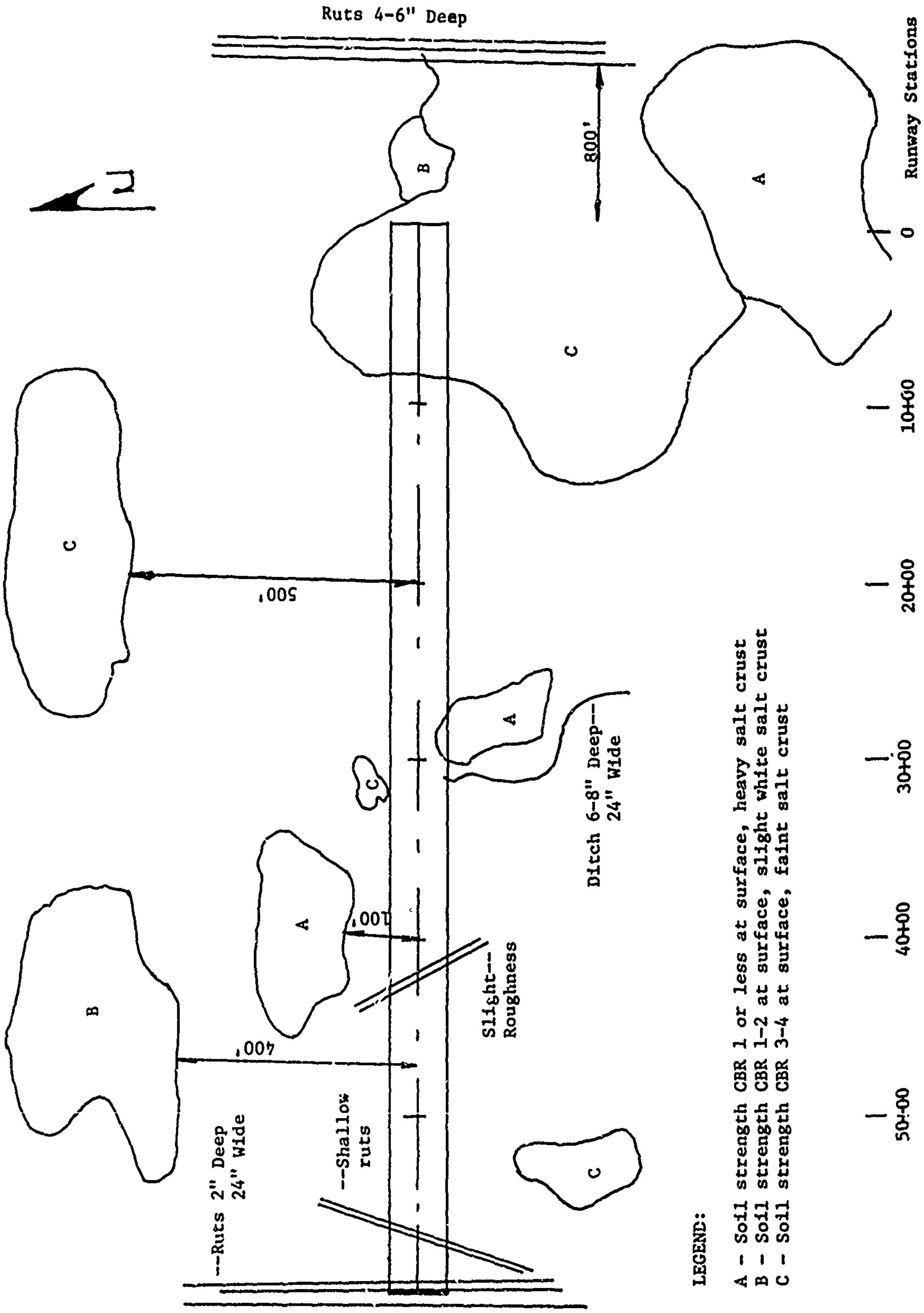
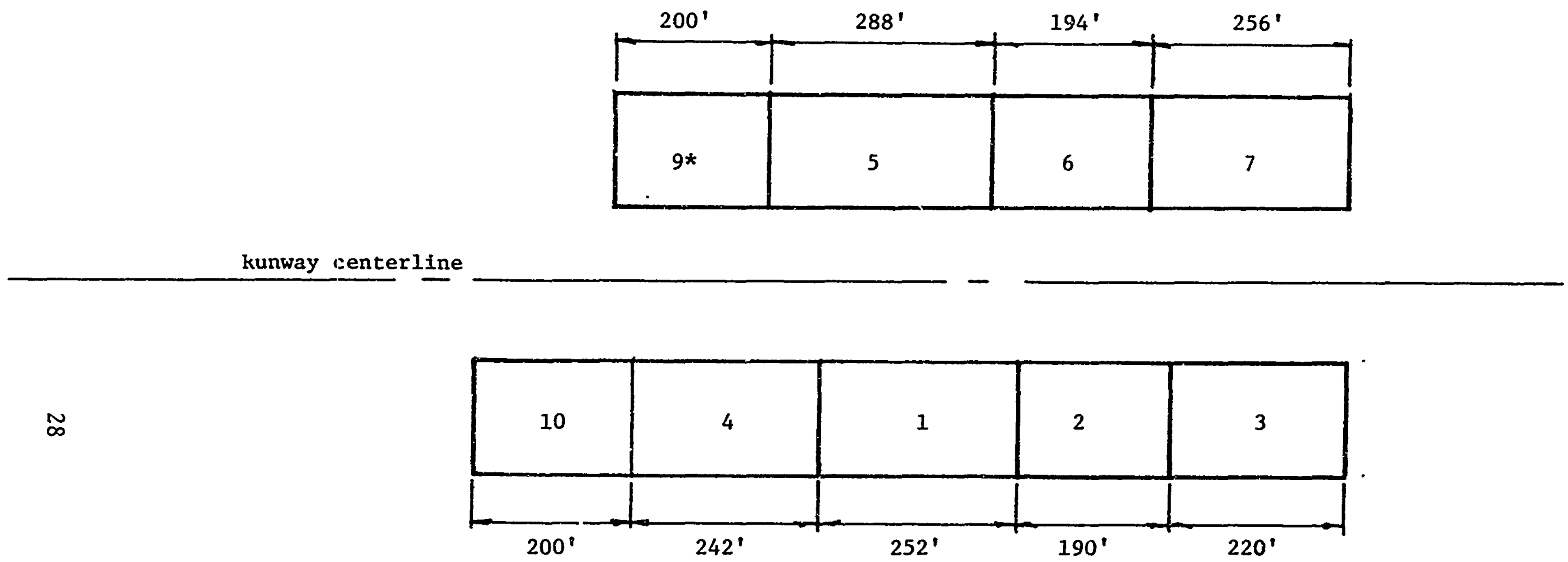


Figure 14. Layout of Test Runway, Harper Lake

Table III

APPLICATION OF DUST SUPPRESSANT TEST ITEMS, HARPER LAKE

Item no.	Material and amount	Width-length (ft)	Area (yd^2)	Application rate (gal/yd^2)
1	Cutback asphalt MC-70, 500 gal; JP-4, 500 gal	50 x 252	1400	0.71
2	Cutback asphalt MC-70, 250 gal; JP-4, 125 gal	42 x 190	887	0.42
3	Cutback asphalt MC-70, 250 gal	39 x 220	953	0.26
4	JP-4, 250 gal	47 x 242	1242	0.20
5	Asphalt emulsion SS-2, 450 gal; water, 450 gal	39 x 288	1248	0.72
6	Asphalt emulsion SS-2, 250 gal; water, 125 gal	36 x 194	776	0.48
7	Asphalt emulsion SS-2, 300 gal	36 x 256	1024	0.29
9	Coherex, 200 gal; water, 400 gal	39 x 200	866	0.69
	Coherex, 385 gal; water, 385 gal			0.89
10	Coherex, 130 gal; water, 900 gal	37 x 200	882	1.25
	Coherex, 390 gal; water, 600 gal		902	1.10



* Number in block indicates test item number.

Figure 15. Layout of Dust Suppressant Test Sections

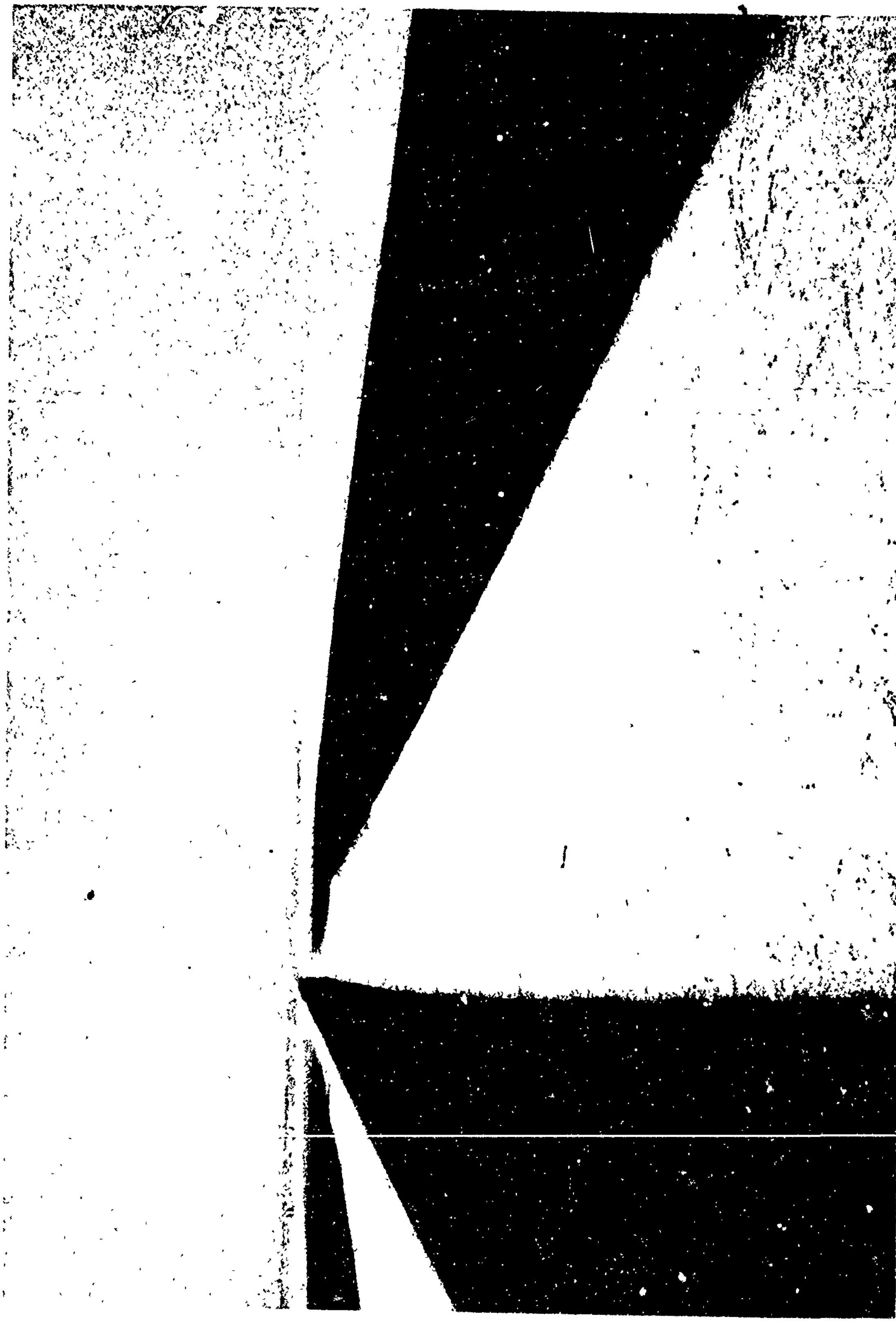


Figure 16. Dust Suppressants, Harper Lake

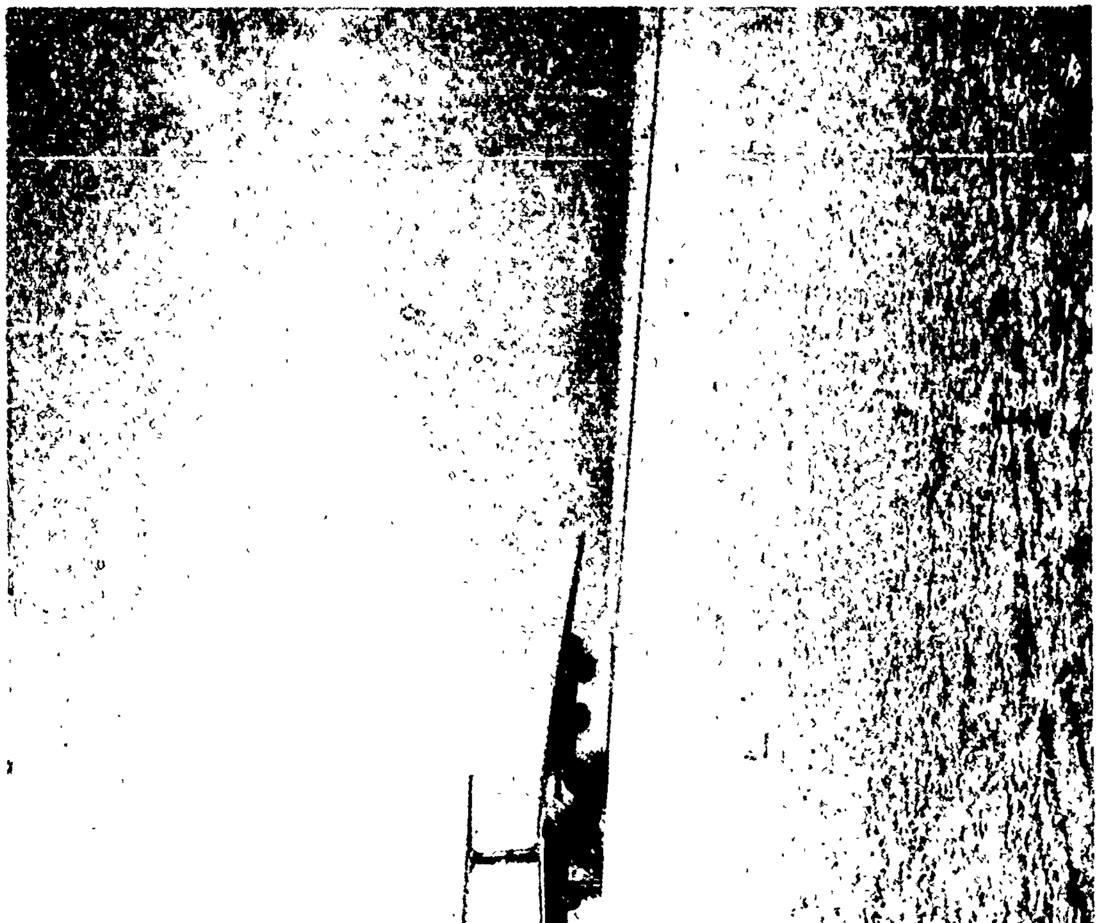


Figure 17. C-141A During Unsurfaced Runway Operations

This was followed by two takeoffs and landings and a slow-speed taxi over deflection measuring devices. The final takeoff was then performed. The results of the flight tests were reported by Lockheed-Georgia Company (Ref. 1).

d. Other Measurements

A 2-foot interval profile of the runway centerline was made prior to the flight tests. The profile was taken in the rut made by the asphalt distributor truck when placing the center line stripe, so no surface crust was present. The tabulated profile data are included in the Appendix. This profile was provided to Lockheed-Georgia Company for use as data input for a dynamic model of the C-141A. The theoretical dynamic responses were compared with the actual dynamic responses obtained during the flight tests. A 2-foot interval profile of the 8000-foot runway laid out by the PRIME BEEF team was made and is available at AFWL.

Rut depth measurements were made at 500-foot intervals along the runway following the flight tests. A number of measurements were made at each location. The measurements were made by placing a straightedge over the rut and flush with the soil surface and measuring from the straightedge to the bottom of the rut (figure 18). The loose material in the rut was removed before making the depth measurement. The results of these measurements are shown in table IV.

Three deflection measurement devices were installed on the runway. The devices consisted of a 1/2-inch by 10-foot steel rod placed in the soil and covered with a 6-inch by 6-inch steel cap. The steel rod was forced into the ground with the top of the rod slightly below the surface. The steel cap was placed on the rod and both were forced down until the top of the cap was flush with the soil surface. The aircraft was taxied over the steel plate and rod. Elevation readings were taken on the plate and rod before and after the aircraft taxied over them. The differences between the initial and final cap elevations were the rut depths, the difference between the initial and final rod elevations was the total deflection caused by the aircraft, and the difference between the total deflection and rut depth was the elastic recovery of the soil. A schematic of the deflection measuring device is shown in figure 19. Data were obtained on only one device, located at station 10 + 00. The total deflection was 0.84 inch, rut depth 0.60 inch, and elastic recovery of the soil 0.24 inch. The cap of one of the deflection devices following the aircraft taxi was shown in figure 12.

Figure 18. Rut Depth Measurement

Table IV

C-141A BARE SOIL FLIGHT TEST, HARPER LAKE, MAIN LANDING GEAR AVERAGE RUT DEPTHS
(inches)

Runway Station	Single pass	Multiple pass
0 + 00	2.2	1.3
5 + 00	1.3	1.6
10 + 00	1.1	2.0
15 + 00	1.4, 2.5	2.0
20 + 00	0.9	2.3
25 + 00	1.1	2.9
30 + 00	0.9, 4.5	
35 + 00	0.8, 2.3	2.5
40 + 00	0.7	2.6
45 + 00	0.7	2.5
50 + 00	0.8	
55 + 00	0.7	
60 + 00	1.0	
63 + 00	1.7	
0 + 00 (nose landing gear)	2.4	
Average	1.5	2.2

Where two numbers appear, measurements were taken at two different locations with different soil strengths.

Station 0 + 00 was the east end of the runway.

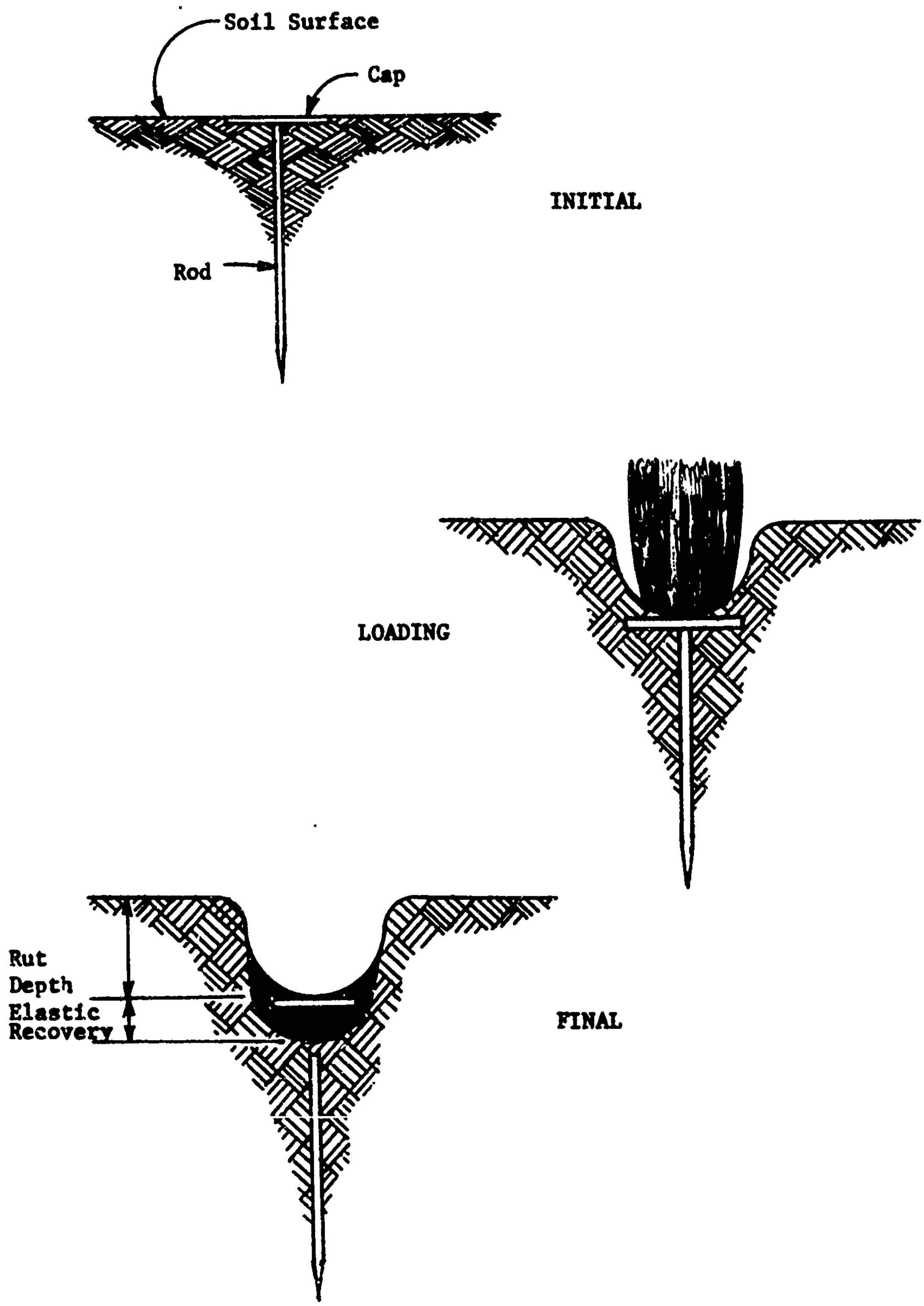


Figure 19. Deflection Measurement Device

SECTION III

DISCUSSION

1. LANDING MAT RUNWAY TEST

a. Effect of C-141A Operations

The overall performance of the landing mat runway was satisfactory during the C-141A flight test program. The performance of the anchoring system, H-rails, and XM19 replacement panels was unsatisfactory. The anchoring system consists of edge anchor connectors that fit the edge or end connectors of the landing mats and a 25-inch-long screw-type anchor stake (figure 20). The edge anchor connectors have an open "U" slot for the anchor stakes. Only a slight amount of mat movement is necessary for the anchor stakes and edge anchor connectors to become separated. Once the stakes and edge connectors become separated, the anchoring system is not functional. H-rails were used to connect one leg of the south turnaround to the runway and also on one of the fillets on the turnaround where the mat connectors did not match and a key lock could not be used. The aircraft operations on the turnaround caused shifting of the mats and the mats at the H-rail became separated by 2 to 8 inches. This separation did not cause any serious problems, but the exposed edges of the H-rails are a source of tire damage. The H-rail separation is shown in figure 21. If operations continued to separate the landing mat surfaces, the mats would have to be pushed back together to maintain continuity in the runway surface and to prevent the jet blast from lifting the mats from the surface. A positive connection is needed at all locations where the mat must be joined. The XM19 replacement panels placed in the runway could not be disassembled for removal from the runway at the completion of the tests.

Limited damage occurred to the landing mat during the flight operations. The mat damage recorded after flight operations included seven weld breaks at the AM2 end joints, two broken C-rails on XM19 mats and bent adaptors between the XM19 and AM2 mat. A weld break on the AM2 is shown in figure 22; this is a typical problem that occurs with the AM2 mat and the mat would have to be replaced in time if operations were continued on the runway. One of the broken C-rails on the XM19 mat is shown in figure 23. A bent adaptor between the XM19 and AM2 mats is shown in figure 24. This deformation was apparently caused by

Figure 20. Anchorage of Mat

Figure 21. H-Rail Separation

Figure 22. Typical Weld Break on the Overlap End Joint of an AM2 Plank

Figure 23. Typical Broken C-Rail on an XM19 Plank

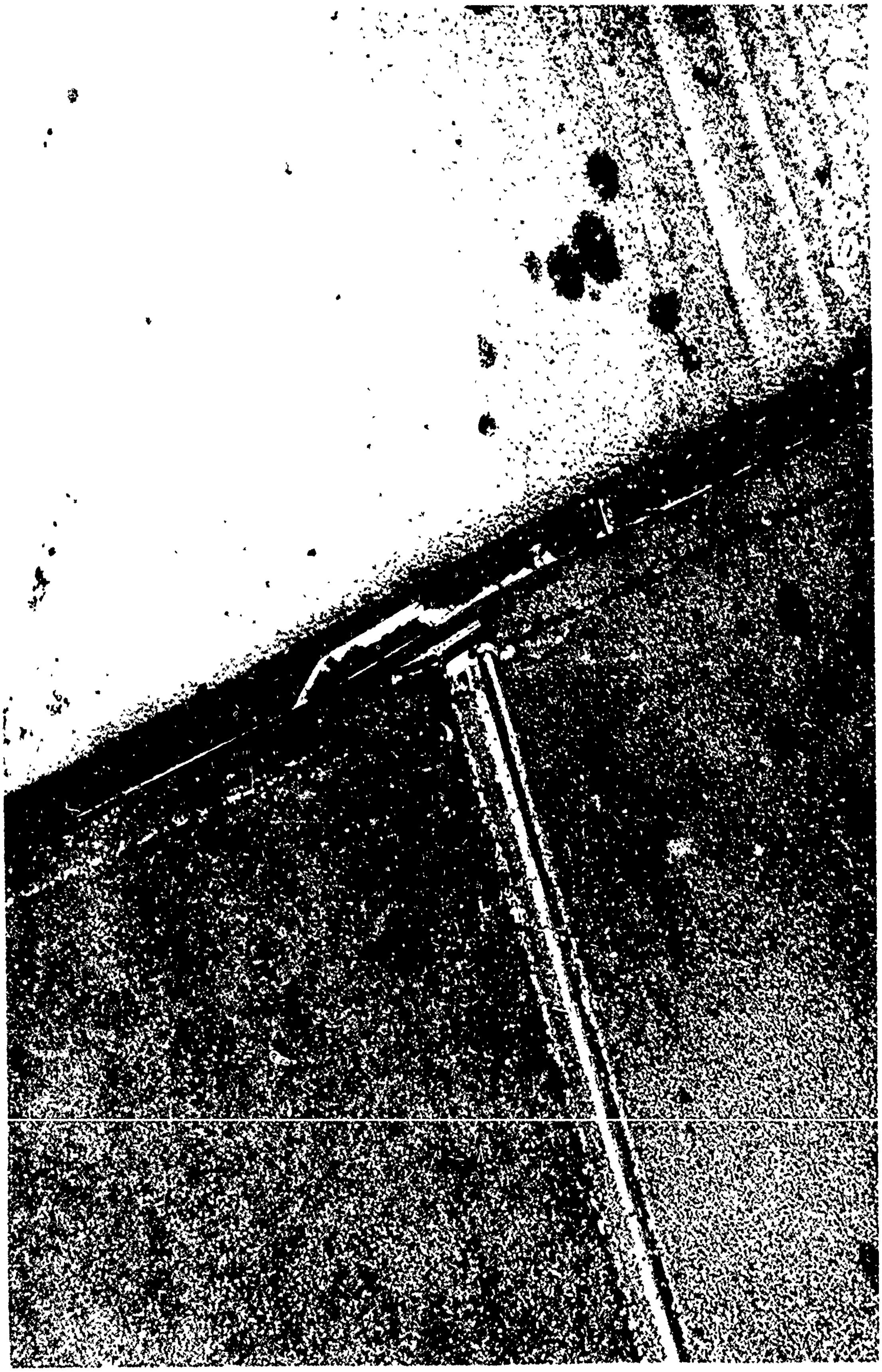


Figure 24. Bent Adaptor between the XM19 and AM2 Matting

the movement of alternate runs of the XM19 mat into the AM2 mat. The C-141A traffic caused longitudinal movement of the landing mats. The XM19 mats were moved 6 to 8 inches with respect to adjacent runs of XM19 mats in the direction of traffic. The movement of the AM2 and XM18 mats was noted by an approximately 8-inch bow that was formed at the centerline (figure 25).

The landing mat runway performed satisfactorily during the test programs; however, the failure of the AM2 end joint welds and the separation of the H-connectors could pose serious problems under extended aircraft operations. These types of failures can cause severe tire damage. The broken end joint welds noted on the landing mat runway had broken 7 to 13 inches across the end joint. These weld breaks occurred in the area of the runway where the greatest amount of mat movement was measured. The greatest bow was measured in the area of the runway where heavy braking was used for full-brake stops. If heavy braking (mat movement) and other aircraft operations had continued, it is most likely that the seven mats with broken welds noted during the last week of flight tests would have failed due to sheared end connectors. Other end connector weld breaks would also probably have developed with continued operation. There was no indication of end-joint failures in the XM18 mat although the bow was approximately the same in both types of mats. Previous tests conducted by the Waterways Experiment Station have indicated that the XM18 end joint is much stronger than the AM2 joint. One method of minimizing the bow developed in the runway is to conduct equal numbers of takeoffs and landings from each end of the runway.

A potential problem could exist with the anchorage of the mats due to the location of the C-141A engines. On the north turnaround three XM19 mats in a fillet were picked up and disconnected by jet blast. This occurred during the application of engine power just prior to takeoff. The outboard engines of the C-141A were approximately 10 feet from the edge of the runway so any exposed edges along the runway perpendicular to the jet blast are especially subjected to the blast. The jet blast also caused severe damage to the dust suppressants used.

The only dust palliative used at the landing mat runway site that performed satisfactorily on both the runway shoulders was DCA-70* reinforced with fiber glass. The polypropylene asphalt membrane did perform adequately

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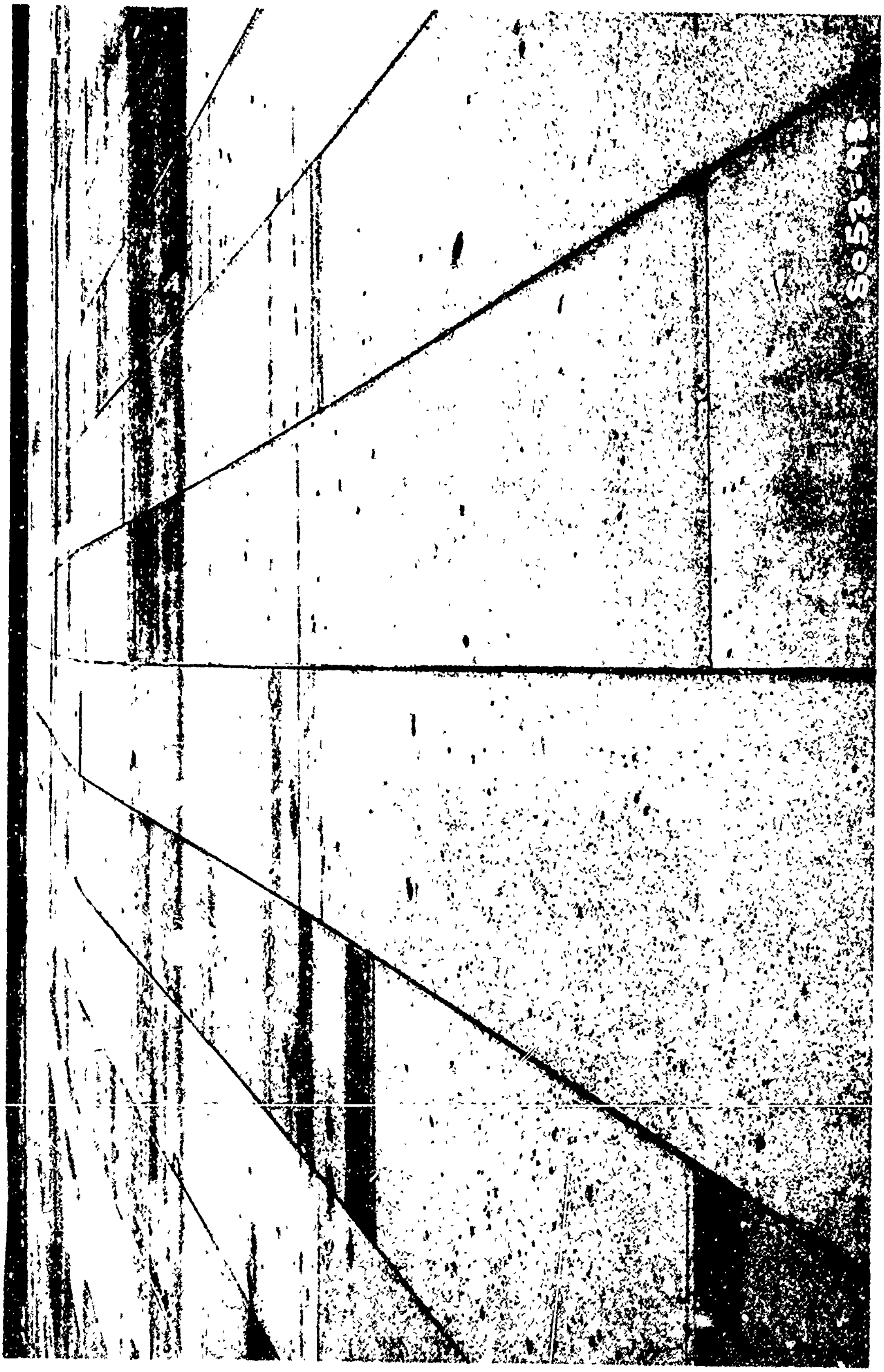

Figure 25. An 8-Inch Bow in the AM2 Matting

on the runway shoulder where it was roof-lapped and anchored so that an edge was not exposed to the jet blast. On the first day of operations when the overruns were subjected to run-up jet blast, approximately 85 percent of the polypropylene on the south half of the north overrun was blown from the soil surface by the jet blast. The jet blast also dislodged the materials on the runway shoulders (figure 26). The Peneprime,* neoprene asphalt emulsion, neoprene asphalt emulsion reinforced with fiber glass, and Dynatech* with and without fiber glass had been almost completely destroyed by the jet blast at the conclusion of the test program. The lack of a dust suppressant on the majority of the runway shoulder did not give rise to any aircraft damage. A complete evaluation of the dust suppressants was conducted by the Waterways Experiment Station (Ref. 5).

The 2.5 percent crown of the landing mat runway did not cause any difficulty in the C-141A operations. The flight crew did not make any adverse comments on the effect of the 2.5 percent crown. Typical cross sections, for each type of mat, of the runway showing the crown are shown in figure 27. Cross sections are shown of the runway subgrade and on the mats before and after the flight tests. This data indicate that the permanent deformation of the runway at the conclusion of flight tests was approximately 0.02 feet, based on elevations taken on the surface of the mat.

As was shown in figure 1, the laying pattern of the XM19 has continuous joints parallel to the runway centerline. The landing gear of the aircraft must travel parallel to these joints. In some cases the wheel will travel directly over the joint. It was noted by visual observation following the flight tests that a permanent deformation had occurred at the joints subjected to the heavy main landing gear traffic. The continuous concentrated traffic had apparently compacted the subgrade along these joints, causing a depression. This could become a problem if the waterproofing material failed and enough deformation occurred to allow collection of water. The soil strengths in this critical area would rapidly deteriorate if water was allowed to enter the soil and the pumping of soil and water through the landing mat joints would cause the depression development to accelerate. The XM19 cross section in figure 26 shows a flattening of the runway crown in the area 8 to 12 feet on each side of the centerline. This type of action would cause serious maintenance problems.

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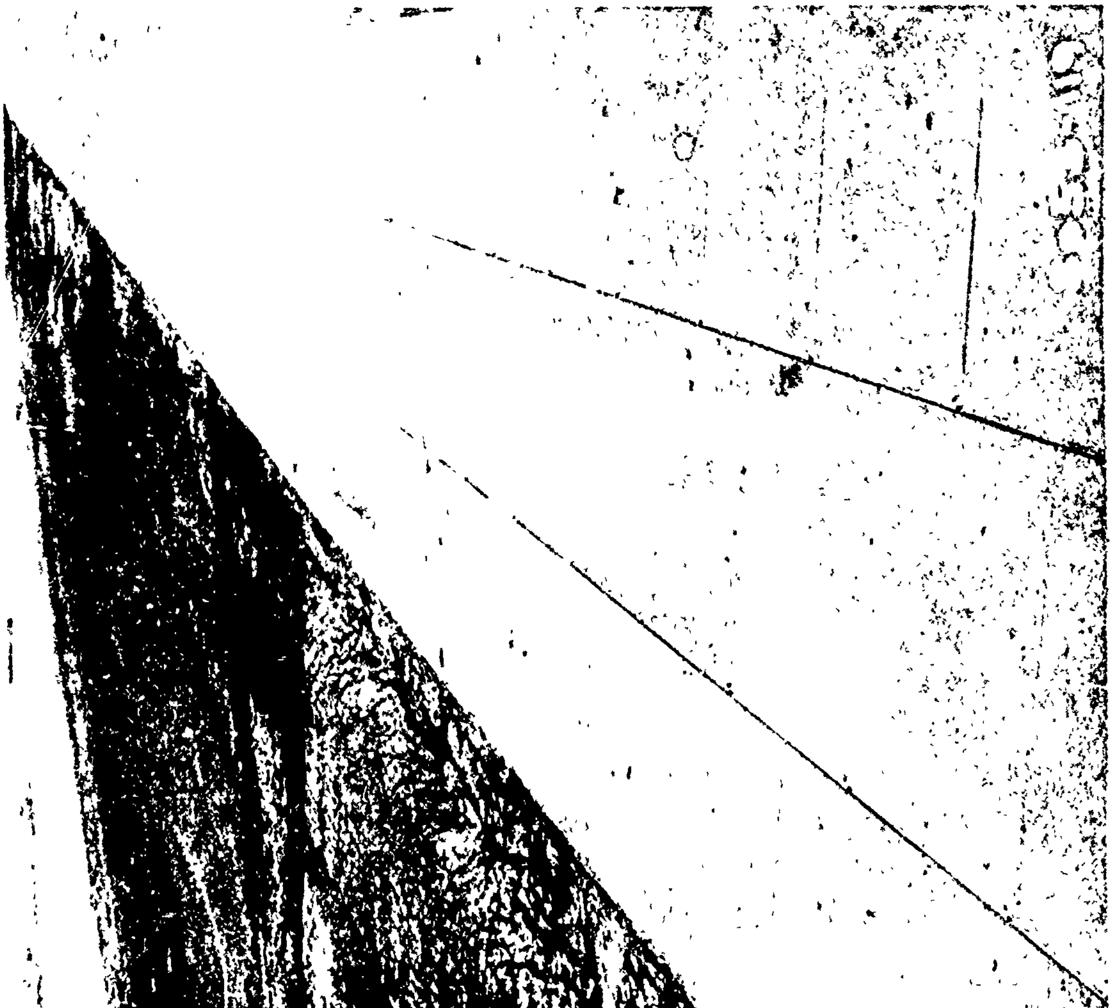


Figure 26. Polypropylene Asphalt Membrane Dust Palliative after Flight Operations

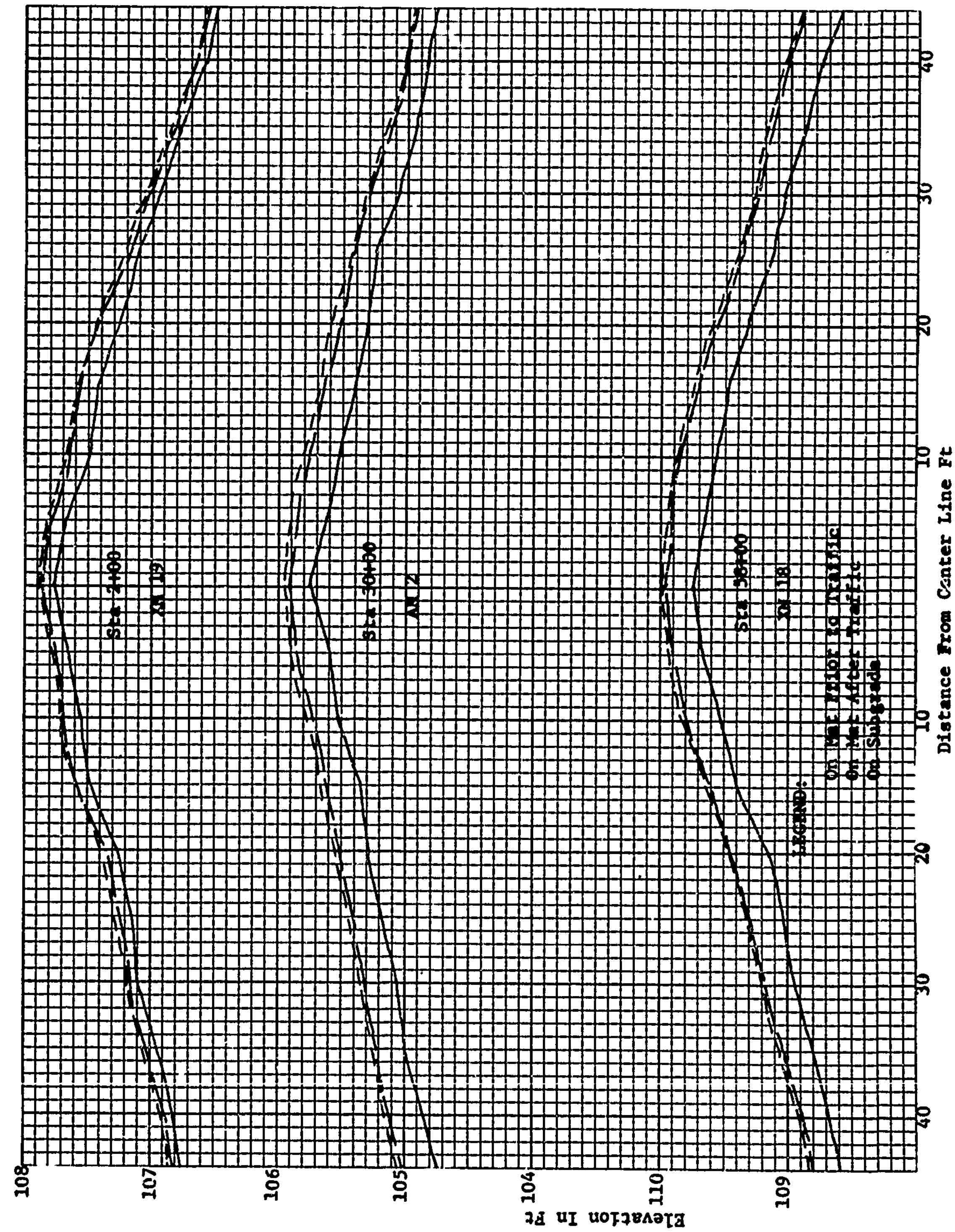


Figure 27. Typical Landing Mat Runway Cross Sections

This type of deformation was not noted on the XM18 and AM2 mats; however, if it was occurring, the mats would bridge the depression because of the laying pattern. Small areas of consolidation of the runway crown were noted under the AM2 and XM18 landing mat, but they were not continuous as under the XM19.

The number of coverages on the landing mat in the runway at Dyess AFB would be difficult to determine. The mat was removed and reused between the Tri-Service Operational Tests and the C-141A tests. The mats were not placed in the same locations so operations on a given area could not be determined. None of the mats completely failed during the testing and a 10 percent replacement rate is allowed when developing landing mat coverage criteria. With continued operation, mat failures such as the AM2 weld breaks could be expected; however, landing mat design criteria show that over 5000 traffic cycles can be expected on a landing mat runway (such as at Dyess AFB) on a subgrade with a CBR of approximately 10. Providing the subgrade strength can be maintained, it would be expected that operations could continue on the Dyess AFB runway for a considerable length of time. The tremendous amount of traffic supported by the landing mat runways in South Vietnam indicates the integrity of this type of runway. In most cases runway failure can occur when the subgrade soil strength is lowered due to excess water. However, if subgrade waterproofing is maintained and adequate drainage is provided, a landing mat runway can provide a nearly semipermanent airfield.

2. UNSURFACED RUNWAY TESTS

a. Flight Operations

The sequence of the tests conducted at Harper Lake was included in the test conduct section (Section II). The operations conducted were the first operations conducted on bare soil with the C-141A. During the tests the aircraft did not stop on the runway, but stopped only on the turnaround areas at each end of the runway. The takeoffs and taxis were started from the stopping point with the engine power being increased as the aircraft rolled onto the runway. Except for the rolling start, standard takeoff procedures were used. Standard landing procedures were used, except for the rollouts on which only limited braking and reverse thrust were used. A complete description of flight operations can be found in reference 1. Taxi turns were made with symmetrical engine power and a maximum steering angle of 45 degrees. Ruts made by both the main gear and the nose gear on the turns are shown in figure 28. The photograph indicates that side slippage of the nose gear occurred on the turns.

Figure 28. C-141A Nose Gear Ruts in Turnaround Area

The runway surface showed considerable rutting following the flight tests. Rut depth measurements were presented in table IV and ranged from 0.7 to 4.5 inches. The average depth of rut for one pass of the landing gear was 1.5 inches with the depths ranging from 0.5 inch to 4.5 inches with the larger rut depths at the lower soil strengths. The average depth of rut for a multiple pass of the gear was 2.2 inches with a range of 1.5 to 3.2 inches. In the areas with the hard dry surface, the surface was broken and pulverized in the ruts. Figure 29 shows the condition of the runway following the tests; the disaggregated and pulverized soil in the rut areas can be seen. In the softer areas, the soil was broken up at the edge of wheels and formed a compacted rut as was shown in figure 13. It was noted by the flight crew that operations conducted after the surface had been pulverized appeared to be much smoother than those at the beginning of the test.

Lockheed-Georgia Company (Ref. 1) reported that "the results of this limited evaluation established the feasibility of operating the C-141A from a bare soil runway without incurring excessive structural loads or propulsion system damage. However, the data was insufficient for developing operational limitations or procedures."

b. Unsurfaced Runway Evaluation Criteria

Criteria for unsurfaced runway operation are necessary for the design and evaluation of unsurfaced runways and for the design of new aircraft landing gear. The latest unsurfaced criteria was developed by the Waterways Experiment Station for the Landing Gear Group, Air Force Flight Dynamics Laboratory (AFFDL-TDR-66-43, Ref. 9). The criteria developed in this study are shown in figure 30. Knowing the aircraft tire pressure, equivalent single-wheel load, and the soil strength (CBR), the number of coverages expected can be determined (a coverage is sufficient passes of load tires in adjacent tire paths to cover a given width of surface area one time).

The maximum equivalent single-wheel load for the C-141A (257,500 pounds nominal gross weight) at Harper Lake was approximately 35,000 pounds. The method for calculating equivalent single-wheel load is given in reference 9. Examples are shown on figure 30 for CBRs of 3 and 10. At a CBR of 3 the nomograph shows that less than one coverage could be expected and approximately 18 coverages at a CBR of 10. In developing the criteria, failure of an unsurfaced runway was considered to occur when the elastic deflection of the soil exceeded 1.5 inches or rutting exceeds 3 inches. But depths were measured up to 4.5

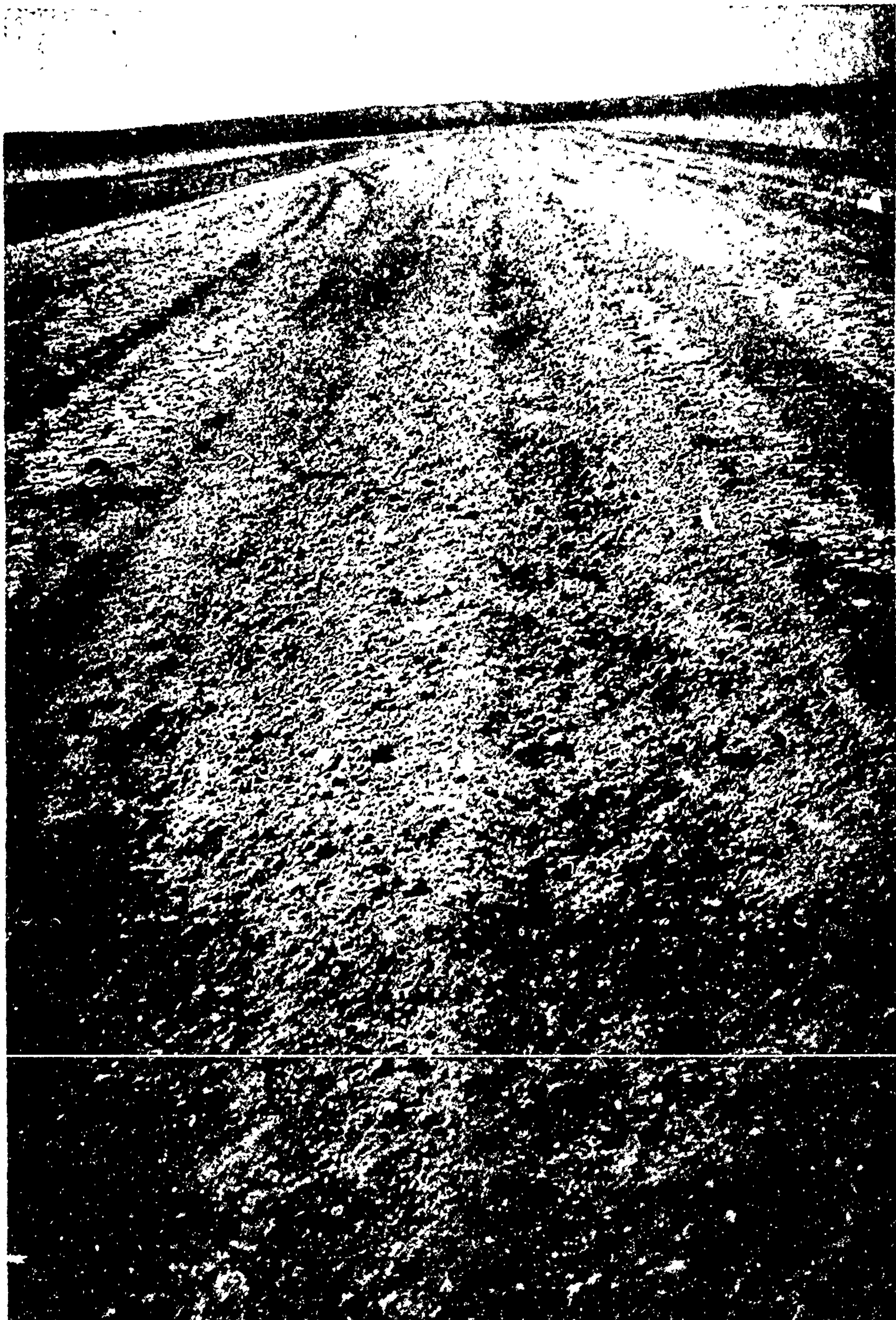


Figure 29. Unsurfaced Runway Following C-141 Operations

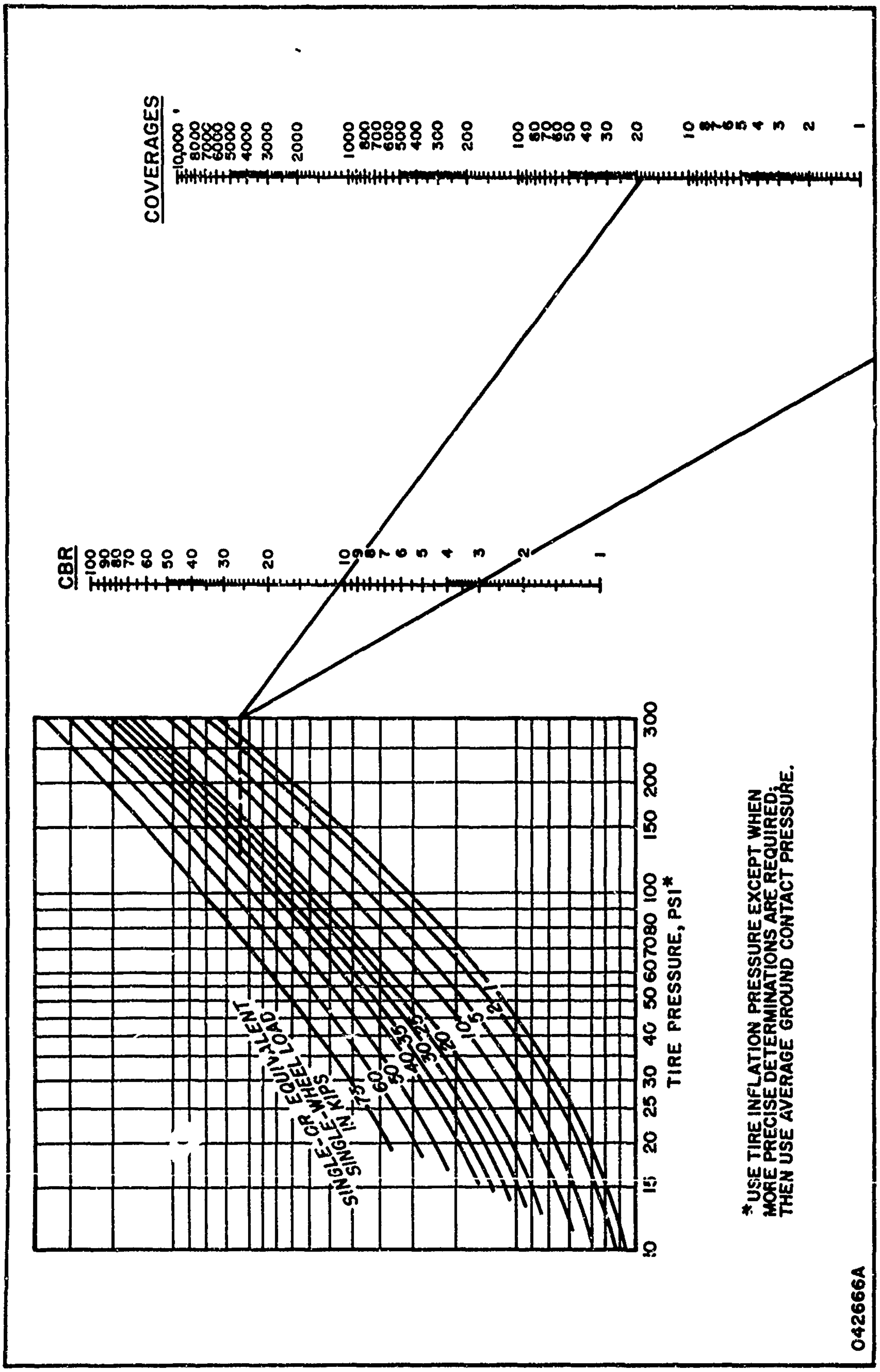


Figure 30. CBR Required for Operation of Aircraft on Unsurfaced Soils

inches at Harper Lake; these areas would be considered failed, based on the above criteria. Elastic deflection was determined at only one location and did not exceed the failure criteria. Even though ruts were formed near or greater than the failure criteria, the aircraft did not experience operating difficulties. This failure criteria may vary depending on the aircraft being used for the unsurfaced runway operations. Aircraft operations would have to be conducted until operations were no longer considered safe in order to more realistically determine failure criteria.

It was possible for a given point on the Harper Lake runway to receive from 2 to 28 coverages. Fourteen passes were made, and for each pass of a tandem main landing gear a given point is subjected to two load repetitions and the equivalent of two coverages. The aircraft did not follow the same path each time so it is doubtful that any point was subjected to 28 coverages. No difficulty in aircraft operation occurred in areas with a CBR as low as 3, although rutting approached the failure criteria, where less than one coverage could be expected (based on existing criteria) and at least two coverages were applied. This indicates that the present unsurfaced evaluation criteria is conservative. The condition of the runway at the conclusion of the test was such that it appeared that aircraft operations could have continued with no operating problems. The loose surface material formed in the ruts would cause an increasing dust problem if operations were continued without some type of effective dust control.

c. Dust Suppression

A concern of Lockheed-Georgia Company was the possibility of foreign object damage (FOD) caused by ingestion of material from the surface of the bare soil runway. The use of reverse thrust probably presents the most critical condition for FOD. It was reported (Ref. 1) that reverse thrust up to a maximum of three-quarter-throttle was used and maintained down to approximately 40 knots during the tests at Harper Lake without major reingestion problems. Previous tests on unsurfaced clay soil runways have indicated no problems due to FOD or ingestion of dust (Refs. 6, 7, 8). Operations on runways with coarse-grained soil (sand) have indicated that the ingestion of the sand is a serious problem.

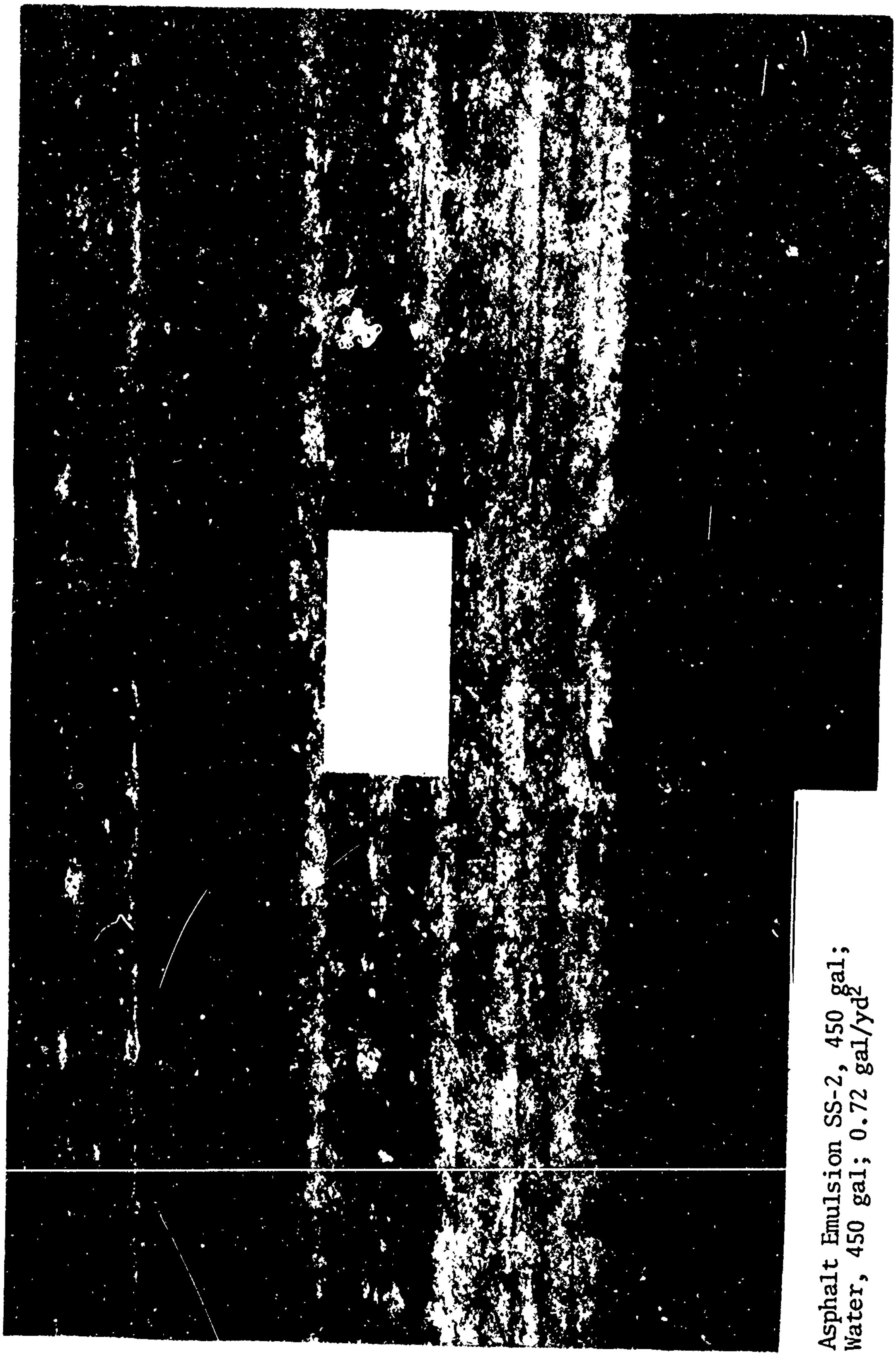
The problem of dust is caused by both jet blast and the disturbance of the soil by the wheels of the aircraft landing gear. Observation of movies made of the tests at Harper Lake indicated that for landings and slow-speed

taxis the major portion of the dust was generated primarily by the interaction of the wheels and the soil. On takeoffs and high-speed taxis both the action of the wheels and the jet blast contributed highly to the dust cloud formed. The movies also indicated some slight dust formation ahead of the engines during the last landing when reverse thrust was being used. The dust on a clay site should not present severe engine maintenance problem. On a sand site, careful monitoring of reverse thrust operation to terminate operation as soon as dust starts to form ahead of the engines should prevent serious ingestion from occurring. The length of time for the reverse thrust procedure could then be varied depending on landing speed and dust consistency.

A large fine dust cloud was formed behind the aircraft during all the operations except for a slow-speed taxi and when the aircraft was parked with the engines at an idle. The dust cloud dissipated within 2 to 3 minutes. With a complete absence of wind, the dissipation of a dust cloud could take a considerable length of time, hampering consecutive operations. The dust cloud at Harper Lake did not present any problems; however, if more than one aircraft were operating in the same type of situation, visibility could be a serious problem for consecutive operations within a short time period. No jet blast erosion of large soil particles was noted.

In order to study methods of preventing the formation of dust clouds and foreign object damage, nine small dust-suppressant test sections were placed on the bare soil runway. The materials were petroleum products and are listed in the test conduct section of this report. Little or no penetration of the dry soil surface by the dust suppressants was achieved. It appeared that considerable wetting of the surface soil would be required to achieve penetration. The materials provided no or limited protection where they were trafficked by the landing gear tires. The materials were on the surface only and were essentially destroyed when the wheel rut was formed. Figure 31 shows item 5 (asphalt emulsion--water mixture 1:1, 0.8 gal/yd^2) where subjected to the aircraft traffic.

It was difficult to determine if the dust suppressants provided any protection to the formation of dust because of the large amount of dust formed by the wheel action. Also, the outboard engines were to the outside of the test sections. In studying the movies of the operations, it appeared that there might have been a slight reduction in the dust cloud when the test sections were traversed. This possible reduction of dust cannot be attributed to a



Asphalt Emulsion SS-2, 450 gal;
Water, 450 gal; 0.72 gal/yd^2

Figure 31. Dust Suppressant Treated Surface Subjected to Aircraft Traffic

specific material because of the relatively small test sections and the speed of the aircraft as it traversed the test sections. To determine if the materials do provide protection against dust formation by jet blast, test sections of at least 150 feet by 500 feet would have to be used. The large test sections would have to be subjected to static aircraft jet blast to eliminate the dust created by the wheel action. Other factors also involved include the type of soil (soil aggregate and particle size), soil moisture, soil compaction, and the presence of loose material on the surface.

Close-up photographs were taken of the test section surfaces before and after the flight operations. The photographs indicated little or no damage to dust suppressant materials other than where subjected to the wheel traffic of the aircraft. Small clods of soil could be seen in the cracks of the surface soil; these clods appeared to be due to the action of the wheels rather than the jet blast because the surface was not disturbed in any areas other than in the wheel ruts.

SECTION IV

CONCLUSIONS

1. LANDING MAT RUNWAY TESTS

a. A polypropylene asphalt membrane provided adequate waterproofing for the landing mat runway subgrade during approximately 2 months of C-141A flight operations.

b. A 2.5 percent crown on the landing mat runway did not cause any aircraft operating problems.

c. DCA-70* reinforced with fiber glass was the only dust suppressant that provided completely adequate protection during the landing mat test program. Polypropylene asphalt membrane lapped to prevent jet blast from getting beneath the membrane also performed satisfactorily.

d. The landing mat anchoring system, H-rain connectors, and XM19 replacement panels did not perform satisfactorily.

e. The failure of AM2 end connector welds would present a hazard to aircraft operations.

f. The permanent deformation of the runway subgrade along the XM19 landing mat joints could cause accelerated deterioration of the runway.

g. Landing mat (AM2, XM18, XM19) runways with adequate subgrade strengths can support continued operation of the C-141A aircraft.

2. UNSURFACED RUNWAY TESTS

a. C-141A operations were successfully conducted on an unsurfaced runway with CBRs ranging from 2 to 20.

b. Ruts formed by the C-141A on the bare soil runway in low-strength areas exceeded existing failure criteria with no resulting operational problems.

c. Existing unsurfaced runway evaluation criteria are conservative, based on the C-141A tests at Harper Lake, California.

*Product names are included for the reader's benefit only and do not indicate endorsement or preferential treatment by the US Air Force.

d. Dust created by C-141A aircraft operations on an unsurfaced runway did not present operational problems.

e. Asphaltic dust suppressants did not provide adequate protection where subjected to C-141A traffic on an unsurfaced runway.

SECTION V

RECOMMENDATIONS

1. LANDING MAT RUNWAY TESTS

A landing mat runway test facility should be maintained for testing both new landing mats and aircraft and the compatibility between landing mats and aircraft operations.

2. UNSURFACED RUNWAY TESTS

a. Flight tests with the C-141A should be conducted to determine unsurfaced runway failure criteria. The failure mode must be defined based on roughness, excessive aircraft structural loading, gear drag loads (rutting), soil deformation, or a combination of these factors. The accurate definition of failure must be defined before evaluation criteria can be adequately developed.

b. A study should be conducted using closely controlled soil strength and instrumented test sections subjected to C-141A gear loads using a load cart to determine unsurfaced runway criteria. Unsurfaced runway criteria cannot be developed using actual aircraft flight tests. To develop criteria, uniform soil and loading conditions are required. It is impossible to locate a site having constant and uniform soil strengths in an area large enough to accomodate flight operations. It is not economically feasible to rework the soil over such a large area to obtain uniform soil strengths. An unsurfaced runway is also exposed to weather conditions (i.e., rain) which can radically change soil strengths. Protection from weather can be provided by using small protected test sections.

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APPENDIX

C-141A BARE SOIL GROUND FLOTATION TEST RUNWAY CENTERLINE PROFILE, HARPER LAKE, CALIFORNIA
(Stations at 2-foot intervals)

Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.
0+00	100.00	0+80	100.01	1+60	100.02	2+40	100.06	3+20	100.10	4+00	100.10
	.01		.01		.03		.05		.09		.09
	.02		.02		.04		.05		.08		.09
	.02		.01		.02		.05		.08		.09
	.01		.00		.01		.05		.08		.09
0+10	100.02	0+90	100.00	1+70	100.03	2+50	100.06	3+30	100.08	4+10	100.08
	.03		.00		.04		.07		.09		.08
	.02		.00		.03		.06		.09		.07
	.02		.01		.02		.05		.09		.07
	.02		.02		.02		.05		.09		.09
0+20	100.02	1+00	100.03	1+80	100.02	2+60	100.05	3+40	100.09	4+20	100.09
	.02		.02		.01		.03		.09		.08
	.01		.02		.00		.02		.10		.08
	.00		.02		.01		.03		.09		.09
	99.99		.03		.02		.04		.09		.10
0+30	100.01	1+10	100.03	1+90	100.02	2+70	100.04	3+50	100.09	4+30	100.12
	.02		.04		.03		.04		.10		.11
	.02		.03		.03		.05		.10		.09
	.01		.03		.04		.06		.10		.09
	.00		.02		.04		.04		.09		.10
0+40	100.00	1+20	100.02	2+00	100.04	2+80	100.02	3+60	100.09	4+40	100.11
	.00		.02		.03		.03		.08		.12
	.00		.01		.03		.04		.07		.11
	.01		.01		.03		.04		.08		.09
	.02		.01		.04		.03		.09		.09
0+50	100.02	1+30	100.01	2+10	100.04	2+90	100.03	3+70	100.09	4+50	100.09
	.01		.02		.04		.03		.09		.10
	.02		.02		.03		.03		.08		.10
	.03		.02		.03		.05		.08		.10
	.02		.02		.03		.05		.08		.10
0+60	100.01	1+40	100.02	2+20	100.03	3+00	100.03	3+80	100.09	4+60	100.10
	.01		.02		.05		.05		.09		.09
	.02		.03		.06		.08		.10		.08
	.02		.03		.04		.08		.09		.09
	.02		.03		.03		.08		.09		.10
0+70	100.01	1+50	100.03	2+30	100.03	3+10	100.07	3+90	100.09	4+70	100.10
	.00		.04		.04		.06		.09		.09
	.02		.03		.05		.06		.09		.10
	.04		.02		.06		.06		.09		.11
	.02		.02		.06		.08		.09		.10

Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.
4+80	100.08	5+70	100.10	6+60	100.15	7+50	100.17	8+40	100.22	9+30	100.24
	.09		.11		.15		.17		.22		.26
	.09		.12		.14		.17		.23		.26
	.08		.12		.14		.18		.23		.26
	.07		.12		.15		.17		.24		.26
4+90	100.07	5+80	100.11	6+70	100.15	7+60	100.17	8+50	100.23	9+40	100.27
	.07		.12		.14		17		.22		.27
	.09		.13		.15		.18		.22		.27
	.10		.13		.16		.18		.22		.27
	.10		.14		.16		.19		.22		.27
5+00	100.10	5+90	100.13	6+80	100.17	7+70	100.18	8+60	100.23	9+50	100.27
	.10		.12		.17		.17		.23		.26
	.10		.12		.17		.17		.24		.26
	.10		.13		.17		.18		.24		.26
	.10		.13		.17		.17		.23		.26
5+10	100.10	6+00	100.14	6+90	100.16	7+80	100.16	8+70	100.23	9+60	100.27
	.10		.13		.16		.17		.22		.27
	.10		.13		.16		.18		.22		.27
	.09		.13		.15		.18		.22		.27
	.11		.13		.16		.19		.22		.28
5+20	100.12	6+10	100.13	7+00	100.16	7+90	100.19	8+80	100.23	9+70	100.26
	.10		.13		.15		.19		.23		.25
	.09		.13		.14		.18		.22		.25
	.10		.13		.15		.17		.23		.26
	.10		.14		.16		.18		.24		.26
5+30	100.10	6+20	100.14	7+10	100.16	8+00	100.19	8+90	100.23	9+80	100.26
	.11		.14		.17		.21		.23		.26
	.12		.14		.17		.22		.23		.27
	.14		.14		.16		.22		.24		.27
	.13		.14		.16		.22		.24		.27
5+40	100.10	6+30	100.14	7+20	100.17	8+10	100.22	9+00	100.23	9+90	100.27
	.11		.14		.17		.22		.23		.26
	.11		.14		.18		.20		.23		.26
	.11		.14		.17		.19		.24		.26
	.12		.14		.16		.21		.25		.26
5+50	100.11	6+40	100.15	7+30	100.16	8+20	100.22	9+10	100.25	10+00	100.25
	.11		.15		.17		.22		.25		.25
	.12		.15		.17		.23		.25		.25
	.12		.14		.17		.23		.24		.26
	.12		.13		.17		.22		.24		.28
5+60	100.12	6+50	100.14	7+40	100.18	8+30	100.22	9+20	100.25	10+10	100.28
	.11		.16		.17		.22		.25		.29
	.10		.15		.16		.22		.24		.29
	.11		.15		.16		.22		.24		.28
	.12		.15		.17		.22		.23		.28

Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.
10+20	100.28	11+10	100.30	12+00	100.34	12+90	100.33	13+80	100.29	14+70	100.25
	.28		.30		.34		.33		.29		.24
	.27		.31		.34		.33		.29		.24
	.28		.32		.34		.33		.29		.25
	.29		.32		.33		.33		.29		.25
10+30	100.29	11+20	100.31	12+10	100.33	13+00	100.33	13+90	100.29	14+80	100.24
	.28		.31		.32		.32		.28		.24
	.28		.30		.32		.31		.28		.24
	.28		.30		.33		.31		.29		.24
	.28		.30		.34		.30		.28		.24
10+40	100.29	11+30	100.30	12+20	100.35	13+10	100.30	14+00	100.27	14+90	100.24
	.30		.31		.34		.30		.27		.25
	.31		.31		.33		.30		.27		.25
	.30		.32		.33		.30		.27		.25
	.29		.32		.33		.30		.27		.25
10+50	100.29	11+40	100.32	12+30	100.32	13+20	100.31	14+10	100.27	15+00	100.24
	.29		.32		.31		.31		.27		.27
	.29		.32		.31		.30		.27		.30
	.28		.31		.32		.30		.26		.29
	.28		.30		.32		.29		.26		.28
10+60	100.28	11+50	100.30	12+40	100.32	13+30	100.29	14+20	100.26	15+10	100.28
	.28		.30		.32		.29		.26		.28
	.28		.31		.32		.29		.27		.28
	.28		.32		.32		.29		.27		.28
	.29		.32		.33		.29		.26		.28
10+70	100.29	11+60	100.33	12+50	100.33	13+40	100.29	14+30	100.26	15+20	100.28
	.30		.32		.33		.29		.27		.28
	.30		.31		.33		.30		.27		.27
	.30		.32		.33		.30		.28		.27
	.30		.33		.33		.29		.27		.28
10+80	100.30	11+70	100.33	12+60	100.33	13+50	100.29	14+40	100.26	15+30	100.27
	.30		.32		.33		.30		.27		.26
	.30		.32		.33		.30		.28		.26
	.30		.33		.33		.29		.28		.25
	.30		.33		.33		.29		.27		.25
10+90	100.30	11+80	100.33	12+70	100.33	13+60	100.29	14+50	100.27	15+40	100.26
	.30		.32		.34		.29		.27		.26
	.30		.31		.34		.29		.27		.27
	.29		.31		.33		.29		.27		.26
	.29		.31		.33		.29		.27		.25
11+00	100.30	11+90	100.31	12+80	100.33	13+70	100.29	14+60	100.28	15+50	100.25
	.30		.32		.32		.28		.28		.25
	.29		.32		.31		.28		.27		.25
	.29		.31		.32		.28		.27		.25
	.30		.33		.33		.28		.27		.25

Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.
15+60	100.24	16+50	100.15	17+40	100.13	18+30	100.18	19+20	100.14	20+10	100.03
	.24		.15		.12		.18		.14		.02
	.24		.15		.11		.18		.14		.02
	.24		.15		.11		.17		.13		.02
	.24		.14		.12		.17		.11		.02
15+70	100.24	16+60	100.13	17+50	100.12	18+40	100.17	19+30	100.11	20+20	100.01
	.23		.13		.13		.17		.12		.01
	.23		.14		.13		.18		.12		.00
	.24		.14		.13		.18		.11		99.99
	.24		.14		.13		.18		.11		.98
15+80	100.23	16+70	100.14	17+60	100.14	18+50	100.18	19+40	100.11	20+30	99.98
	.22		.14		.14		.18		.11		.98
	.21		.14		.13		.18		.10		.98
	.21		.15		.13		.18		.10		.97
	.21		.15		.14		.18		.11		.97
15+90	100.21	16+80	100.15	17+70	100.14	18+60	100.17	19+50	100.10	20+40	99.97
	.20		.15		.13		.17		.09		.96
	.20		.15		.13		.17		.09		.95
	.20		.15		.13		.17		.09		.95
	.19		.15		.13		.16		.09		.95
16+00	100.18	16+90	100.15	17+80	100.14	18+70	100.16	19+60	100.09	20+50	99.93
	.18		.14		.14		.16		.09		.92
	.18		.14		.15		.16		.08		.92
	.18		.15		.15		.15		.08		.92
	.19		.15		.15		.15		.07		.92
16+10	100.19	17.00	100.14	17+90	100.15	18+80	100.15	19+70	100.07	20+60	99.91
	.18		.14		.16		.15		.07		.90
	.18		.15		.16		.16		.07		.89
	.19		.14		.16		.16		.06		.88
	.19		.13		.16		.15		.06		.87
16+20	100.18	17+10	100.13	18+00	100.15	18+90	100.15	19+80	100.06	20+70	99.87
	.18		.14		.17		.15		.06		.87
	.18		.14		.20		.15		.06		.87
	.18		.13		.18		.15		.06		.86
	.17		.14		.17		.15		.05		.85
16+30	100.17	17+20	100.15	18+10	100.17	19+00	100.15	19+90	100.05	20+80	99.84
	.16		.15		.17		.15		.05		.84
	.16		.14		.17		.15		.05		.84
	.16		.14		.17		.15		.05		.84
	.16		.14		.18		.15		.05		.83
16+40	100.16	17+30	100.14	18+20	100.19	19+10	100.15	20+00	100.05	20+90	99.83
	.16		.14		.19		.15		.05		.82
	.16		.14		.20		.15		.04		.81
	.16		.14		.19		.15		.04		.80
	.15		.14		.18		.15		.03		.80

Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.
21+00	99.80	21+90	99.83	22+80	99.82	23+70	99.86	24+60	99.96	25+50	99.97
	.83		.83		.82		.87		.96		.97
	.87		.83		.82		.87		.96		.97
	.87		.82		.82		.87		.96		.96
	.86		.82		.82		.87		.97		.96
21+10	99.86	22+00	99.82	22+90	99.82	23+80	99.88	24+70	99.97	25+60	99.97
	.87		.82		.82		.88		.97		.97
	.87		.82		.82		.88		.97		.96
	.87		.82		.81		.88		.96		.96
	.87		.82		.81		.87		.96		.97
21+20	99.87	22+10	99.82	23+00	99.81	23+90	99.87	24+80	99.97	25+70	99.97
	.87		.82		.82		.88		.97		.97
	.86		.82		.83		.88		.96		.97
	.86		.83		.83		.89		.96		.96
	.86		.83		.83		.89		.97		.96
21+30	99.86	22+20	99.82	23+10	99.83	24+00	99.89	24+90	99.97	25+80	99.98
	.86		.82		.84		.88		.97		.98
	.86		.83		.84		.87		.97		.97
	.85		.83		.84		.88		.96		.97
	.85		.82		.84		.90		.96		.98
21+40	99.84	22+30	99.82	23+20	99.84	24+10	99.90	25+00	99.97	25+90	99.98
	.84		.82		.84		.91		.97		.98
	.84		.82		.84		.91		.96		.98
	.84		.82		.84		.91		.96		.98
	.85		.82		.85		.91		.95		.98
21+50	99.85	22+40	99.82	23+30	99.85	24+20	99.91	25+10	99.95	26+00	99.98
	.85		.82		.86		.91		.96		.98
	.85		.82		.86		.91		.96		.97
	.85		.82		.85		.91		.95		.97
	.85		.81		.85		.91		.95		.96
21+60	99.85	22+50	99.81	23+40	99.85	24+30	99.91	25+20	99.96	26+10	99.96
	.85		.82		.85		.91		.96		.96
	.84		.82		.85		.91		.96		.96
	.84		.82		.85		.92		.96		.97
	.84		.82		.85		.92		.96		.97
21+70	99.84	22+60	99.81	23+50	99.85	24+40	99.92	25+30	99.96	26+20	99.98
	.83		.81		.85		.92		.96		.98
	.83		.82		.85		.92		.96		.98
	.82		.82		.85		.92		.97		.98
	.82		.81		.85		.93		.97		.98
21+80	99.82	22+70	99.81	23+60	99.85	24+50	99.93	25+40	99.96	26+30	99.98
	.82		.81		.85		.94		.96		.96
	.82		.81		.85		.94		.97		.96
	.82		.81		.85		.95		.97		.97
	.83		.81		.86		.95		.97		.97

Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.
26+40	99.97	27+30	100.00	28+20	100.08	29+10	100.20	30+00	100.13	30+90	100.15
	.97		.00		.08		.20		.14		.16
	.98		.00		.09		.20		.15		.16
	.98		.01		.09		.21		.15		.15
	.98		.01		.10		.21		.14		.15
26+50	99.98	27+40	100.01	28+30	100.11	29+20	100.20	30+10	100.14	31+00	100.15
	.97		.01		.12		.20		.15		.15
	.97		.01		.12		.21		.15		.14
	.98		.01		.12		.21		.14		.15
	.98		.01		.12		.21		.14		.16
26+60	99.98	27+50	100.0.	28+40	100.12	29+30	100.21	30+20	100.14	31+10	100.16
	.98		.01		.13		.21		.14		.16
	.97		.01		.14		.20		.14		.16
	.97		.02		.14		.20		.14		.15
	.98		.02		.15		.20		.14		.15
26+70	99.98	27+60	100.01	28+50	100.15	29+40	100.20	30+30	100.14	31+20	100.14
	.99		.01		.15		.20		.14		.14
	.99		.02		.15		.19		.14		.14
	.98		.02		.15		.19		.14		.14
	.98		.03		.15		.19		.14		.14
26+80	99.98	27+70	100.03	28+60	100.15	29+50	100.19	30+40	100.14	31+30	100.15
	.98		.02		.15		.18		.14		.16
	.98		.02		.16		.18		.14		.16
	.98		.03		.16		.18		.14		.15
	.97		.03		.16		.18		.14		.15
26+90	99.97	27+80	100.02	28+70	100.16	29+60	100.19	30+50	100.14	31+40	100.15
	.97		.02		.17		.19		.15		.15
	.97		.03		.17		.18		.15		.16
	.97		.03		.17		.18		.15		.16
	.97		.04		.17		.17		.15		.16
27+00	99.98	27+90	100.04	28+80	100.17	29+70	100.17	30+60	100.15	31+50	100.16
	.98		.04		.17		.17		.15		.15
	.98		.04		.18		.17		.16		.15
	.98		.05		.18		.17		.16		.16
	.99		.05		.19		.17		.16		.16
27+10	99.99	28+00	100.06	28+90	100.19	29+80	100.17	30+70	100.15	31+60	100.15
	.99		.06		.19		.17		.14		.15
	.99		.07		.19		.16		.14		.14
	.99		.07		.20		.16		.14		.14
	.99		.06		.20		.15		.14		.15
27+20	100.00	28+10	100.06	29+00	100.21	29+90	100.15	30+80	100.15	31+70	100.15
	.00		.07		.20		.14		.15		.15
	.00		.07		.18		.14		.15		.15
	.00		.07		.19		.14		.15		.15
	.00		.07		.20		.14		.15		.15

Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.
31+80	100.16	32+70	100.21	33+60	100.24	34+50	100.15	35+40	100.09	36+30	100.10
	.16		.21		.24		.16		.09		.10
	.15		.21		.24		.16		.09		.10
	.15		.22		.24		.16		.09		.10
	.15		.22		.24		.15		.09		.10
31+90	100.14	32+80	100.21	33+70	100.24	34+60	100.15	35+50	100.09	36+40	100.09
	.13		.21		.23		.15		.09		.09
	.15		.22		.23		.14		.09		.09
	.16		.22		.22		.14		.09		.09
	.17		.23		.22		.15		.09		.09
32+00	100.18	32+90	100.23	33+80	100.21	34+70	100.15	35+60	100.09	36+50	100.09
	.18		.22		.21		.14		.09		.09
	.18		.22		.21		.13		.09		.10
	.17		.22		.21		.12		.09		.10
	.15		.22		.21		.12		.09		.10
32+10	100.15	33+00	100.22	33+90	100.21	34+80	100.11	35+70	100.09	36+60	100.11
	.16		.24		.21		.11		.09		.11
	.16		.27		.21		.10		.09		.11
	.16		.26		.21		.10		.09		.11
	.16		.25		.20		.09		.09		.11
32+20	100.16	33+10	100.25	34+00	100.18	34+90	100.09	35+80	100.09	36+70	100.11
	.17		.25		.18		.09		.09		.11
	.18		.26		.19		.09		.09		.11
	.18		.27		.19		.09		.09		.11
	.18		.27		.20		.09		.10		.11
32+30	100.18	33+20	100.27	34+10	100.20	35+00	100.10	35+90	100.10	36+80	100.11
	.18		.27		.20		.10		.10		.11
	.18		.26		.20		.10		.10		.11
	.18		.26		.19		.10		.10		.12
	.18		.27		.19		.10		.10		.12
32+40	100.19	33+30	100.27	34+20	100.19	35+10	100.10	36+00	100.09	36+90	100.13
	.19		.26		.19		.10		.09		.13
	.18		.26		.18		.10		.09		.14
	.18		.25		.17		.10		.09		.14
	.18		.25		.16		.10		.09		.14
32+50	100.18	33+40	100.26	34+30	100.16	35+20	100.10	36+10	100.09	37+00	100.15
	.19		.25		.16		.10		.09		.15
	.20		.24		.16		.10		.09		.15
	.21		.24		.16		.10		.09		.15
	.21		.25		.15		.10		.09		.15
32+60	100.21	33+50	100.25	34+40	100.14	35+30	100.10	36+20	100.10	37+10	100.14
	.21		.26		.15		.10		.10		.14
	.21		.25		.16		.10		.10		.14
	.21		.24		.16		.10		.10		.14
	.21		.24		.15		.10		.10		.14

Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.
37+20	100.14	38+10	100.19	39+00	100.20	39+90	100.25	40+80	100.27	41+70	100.37
	.14		.20		.20		.26		.27		.36
	.15		.20		.20		.26		.27		.36
	.15		.20		.20		.26		.27		.36
	.15		.21		.21		.26		.27		.36
37+30	100.16	38+20	100.21	39+10	100.21	40+00	100.26	40+90	100.27	41+80	100.36
	.16		.21		.22		.27		.27		.36
	.16		.21		.22		.27		.28		.36
	.16		.21		.23		.28		.29		.36
	.17		.21		.23		.28		.30		.36
37+40	100.17	38+30	100.21	39+20	100.24	40+10	100.29	41+00	100.32	41+90	100.36
	.17		.22		.24		.30		.32		.36
	.17		.22		.24		.30		.32		.36
	.17		.22		.24		.29		.32		.36
	.17		.22		.24		.29		.33		.36
37+50	100.17	38+40	100.23	39+30	100.24	40+20	100.28	41+10	100.33	42+00	100.36
	.17		.23		.24		.28		.34		.35
	.17		.23		.24		.28		.34		.35
	.17		.23		.24		.28		.34		.35
	.17		.23		.24		.28		.34		.34
37+60	100.17	38+50	100.23	39+40	100.24	40+30	100.28	41+20	100.34	42+10	100.34
	.17		.23		.24		.28		.34		.33
	.17		.23		.24		.28		.34		.33
	.17		.23		.24		.28		.35		.33
	.17		.23		.24		.28		.35		.33
37+70	100.17	38+60	100.22	39+50	100.24	40+40	100.29	41+30	100.35	42+20	100.33
	.17		.22		.25		.29		.36		.32
	.17		.22		.25		.29		.36		.32
	.17		.22		.26		.29		.36		.32
	.17		.22		.26		.29		.35		.31
37+80	100.17	38+70	100.22	39+60	100.26	40+50	100.29	41+40	100.34	42+30	100.31
	.17		.22		.26		.29		.34		.30
	.17		.22		.26		.29		.34		.30
	.17		.22		.26		.29		.35		.30
	.17		.22		.26		.29		.35		.31
37+90	100.17	38+80	100.22	39+70	100.26	40+60	100.31	41+50	100.35	42+40	100.32
	.17		.22		.26		.31		.36		.32
	.18		.22		.25		.31		.36		.32
	.18		.22		.25		.31		.36		.32
	.18		.22		.25		.31		.36		.31
38+00	100.18	38+90	100.21	39+80	100.25	40+70	100.31	41+60	100.37	42+50	100.31
	.18		.21		.25		.31		.37		.30
	.19		.21		.25		.30		.37		.30
	.19		.21		.25		.29		.37		.29
	.19		.21		.25		.28		.37		.29

Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.
42+60	100.28	43+50	100.24	44+40	100.24	45+30	100.39	46+20	100.41	47+10	100.46
	.28		.23		.24		.39		.41		.47
	.28		.23		.24		.39		.41		.47
	.28		.23		.25		.39		.41		.48
	.28		.23		.25		.39		.41		.48
42+70	100.28	43+60	100.24	44+50	100.25	45+40	100.36	46+30	100.41	47+20	100.49
	.27		.24		.26		.36		.40		.49
	.27		.24		.26		.36		.40		.49
	.27		.23		.26		.36		.40		.49
	.27		.23		.26		.37		.40		.49
42+80	100.26	43+70	100.23	44+60	100.27	45+50	100.37	46+40	100.41	47+30	100.49
	.26		.22		.27		.38		.41		.50
	.26		.22		.27		.38		.41		.50
	.26		.22		.27		.38		.41		.50
	.26		.21		.27		.37		.41		.51
42+90	100.26	43+80	100.20	44+70	100.27	45+60	100.36	46+50	100.41	47+40	100.52
	.25		.21		.27		.36		.41		.52
	.25		.22		.27		.36		.41		.53
	.25		.22		.27		.36		.41		.53
	.25		.23		.27		.36		.41		.54
43+00	100.24	43+90	100.23	44+80	100.28	45+70	100.37	46+60	100.42	47+50	100.54
	.24		.24		.28		.37		.42		.55
	.25		.24		.28		.37		.42		.55
	.25		.24		.28		.37		.42		.55
	.26		.24		.29		.38		.42		.55
43+10	100.26	44+00	100.23	44+90	100.29	45+80	100.39	46+70	100.42	47+60	100.55
	.27		.23		.30		.39		.41		.55
	.27		.23		.30		.39		.42		.56
	.27		.23		.30		.39		.43		.57
	.27		.23		.31		.39		.44		.58
43+20	100.27	44+10	100.23	45+00	100.32	45+90	100.39	46+80	100.44	47+70	100.59
	.26		.23		.32		.39		.44		.60
	.26		.23		.32		.39		.44		.60
	.25		.23		.32		.39		.45		.60
	.25		.23		.32		.39		.45		.60
43+30	100.24	44+20	100.23	45+10	100.32	46+00	100.40	46+90	100.45	47+80	100.59
	.23		.23		.32		.40		.46		.59
	.23		.23		.33		.40		.46		.60
	.23		.23		.34		.40		.46		.60
	.24		.23		.34		.40		.46		.61
43+40	100.24	44+30	100.23	45+20	100.35	46+10	100.40	47+00	100.45	47+90	100.61
	.24		.23		.35		.41		.45		.62
	.24		.23		.35		.41		.45		.62
	.24		.23		.35		.41		.45		.62
	.24		.23		.35		.41		.46		.61

Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.
48+00	100.61	48+90	100.75	49+80	100.81	50+70	100.80	51+60	100.77	52+50	100.80
	.61		.74		.81		.79		.77		.80
	.62		.74		.81		.79		.77		.80
	.63		.74		.81		.79		.77		.81
	.64		.74		.81		.79		.78		.81
48+10	100.65	49+00	100.74	49+90	100.81	50+80	100.79	51+70	100.78	52+60	100.82
	.66		.74		.80		.79		.79		.82
	.66		.75		.80		.79		.79		.82
	.66		.76		.80		.79		.79		.81
	.66		.77		.80		.79		.79		.81
48+20	100.66	49+10	100.78	50+00	100.81	50+90	100.79	51+80	100.79	52+70	100.81
	.66		.79		.80		.79		.79		.80
	.66		.79		.80		.79		.79		.81
	.66		.79		.80		.79		.79		.82
	.66		.79		.80		.79		.79		.82
48+30	100.66	49+20	100.78	50+10	100.80	51+00	100.78	51+90	100.79	52+80	100.83
	.67		.78		.80		.78		.79		.83
	.68		.79		.80		.78		.79		.82
	.69		.79		.80		.78		.79		.81
	.70		.80		.80		.78		.79		.81
48+40	100.72	49+30	100.80	50+20	100.80	51+10	100.78	52+00	100.79	52+90	100.80
	.72		.81		.80		.79		.79		.80
	.72		.81		.80		.79		.79		.80
	.72		.81		.80		.79		.79		.80
	.71		.81		.81		.79		.79		.80
48+50	100.71	49+40	100.80	50+30	100.81	51+20	100.78	52+10	100.79	53+00	100.79
	.71		.80		.82		.78		.79		.79
	.71		.80		.82		.78		.79		.80
	.71		.80		.82		.78		.79		.81
	.71		.79		.82		.78		.79		.82
48+60	100.72	49+50	100.79	50+40	100.81	51+30	100.78	52+20	100.80	53+10	100.83
	.72		.78		.81		.78		.80		.84
	.72		.78		.81		.78		.80		.84
	.73		.79		.81		.78		.80		.84
	.73		.80		.81		.78		.80		.84
48+70	100.73	49+60	100.81	50+50	100.81	51+40	100.77	52+30	100.80	53+20	100.83
	.74		.81		.82		.77		.81		.83
	.74		.81		.82		.77		.81		.84
	.74		.81		.81		.77		.81		.84
	.74		.81		.81		.77		.81		.85
48+80	100.75	49+70	100.81	50+60	100.80	51+50	100.77	52+40	100.80	53+30	100.85
	.75		.81		.80		.77		.80		.86
	.75		.81		.80		.77		.80		.86
	.75		.81		.80		.77		.80		.85
	.75		.81		.80		.77		.80		.85

Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.
53+40	100.84	54+30	100.79	55+20	100.74	56+10	100.77	57+00	100.83	57+90	100.88
	.84		.78		.74		.78		.83		.89
	.83		.78		.74		.78		.83		.89
	.82		.78		.73		.78		.83		.90
	.81		.78		.73		.78		.83		.90
53+50	100.81	54+40	100.77	55+30	100.73	56+20	100.79	57+10	100.83	58+00	100.91
	.81		.77		.72		.79		.83		.91
	.81		.77		.72		.79		.83		.91
	.82		.77		.73		.79		.83		.92
	.82		.77		.74		.79		.83		.92
53+60	100.83	54+50	100.77	55+40	100.75	56+30	100.79	57+20	100.83	58+10	100.93
	.83		.77		.75		.79		.83		.94
	.83		.77		.74		.79		.83		.94
	.83		.76		.74		.79		.84		.94
	.83		.76		.74		.79		.84		.94
53+70	100.83	54+60	100.75	55+50	100.73	56+40	100.78	57+30	100.84	58+20	100.93
	.83		.75		.73		.78		.85		.93
	.83		.75		.73		.78		.85		.93
	.83		.74		.73		.79		.85		.93
	.83		.74		.73		.79		.85		
53+80	100.82	54+70	100.74	55+60	100.74	56+50	100.79	57+40	100.85	58+30	100.93
	.82		.73		.74		.80		.85		.92
	.82		.73		.74		.80		.85		.92
	.82		.73		.74		.80		.85		.92
	.82		.73		.74		.80		.85		.92
53+90	100.82	54+80	100.72	55+70	100.74	56+60	100.81	57+50	100.85	58+40	100.93
	.81		.72		.74		.81		.84		.93
	.81		.72		.74		.81		.84		.93
	.81		.72		.74		.81		.84		.93
	.81		.72		.74		.82		.84		.94
54+00	100.81	54+90	100.72	55+80	100.74	56+70	100.82	57+60	100.84	58+50	100.94
	.81		.73		.74		.83		.84		.95
	.81		.73		.74		.83		.85		.95
	.81		.73		.74		.82		.86		.95
	.80		.73		.74		.82		.87		.95
54+10	100.80	55+00	100.73	55+90	100.74	56+80	100.81	57+70	100.88	58+60	100.95
	.79		.73		.75		.81		.88		.95
	.79		.73		.75		.81		.88		.96
	.79		.73		.76		.81		.88		.96
	.79		.73		.76		.81		.88		.97
54+20	100.80	55+10	100.73	56+00	100.77	56+90	100.82	57+80	100.88	58+70	100.98
	.80		.73		.77		.82		.88		.98
	.80		.73		.77		.82		.88		.96
	.80		.73		.77		.82		.88		101.06
	.79		.73		.77		.82		.88		.06

Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.
58+80	100.98	59+70	101.08	60+60	101.15	61+50	101.20	62+40	101.29
	.98		.08		.16		.16		.29
	101.00		.08		.15		.17		.31
	.06		.09		.14		.23		.30
	.06		.09		.16		.19		.31
58+90	101.01	59+80	101.10	60+70	101.18	61+60	101.21	62+50	101.31
	.01		.10		.15		.20		.28
	.01		.10		.14		.21		.27
	.02		.10		.16		.19		.33
	.02		.11		.14		.17		.33
59+00	101.03	59+90	101.11	60+80	101.13	61+70	101.15	62+60	101.33
	.03		.12		.14		.24		.30
	.03		.12		.15		.23		.32
	.03		.12		.15		.23		.34
	.03		.12		.15		.23		.29
59+10	101.03	60+00	101.13	60+90	101.14	61+80	101.22	62+70	101.34
	.03		.13		.14		.23		.31
	.03		.13		.15		.24		.33
	.03		.13		.15		.24		.39
	.03		.13		.08		.23		.30
59+20	101.04	60+10	101.12	61+00	101.19	61+90	101.25	62+80	101.38
	.05		.12		.17		.19		.34
	.06		.12		.17		.21		.35
	.07		.12		.13		.25		.34
	.08		.12		.17		.24		.34
59+30	101.08	60+20	101.12	61+10	101.17	62+00	101.27	62+90	101.31
	.09		.12		.14		.26		.34
	.08		.10		.17		.27		.36
	.06		.14		.17		.27		.37
	.06		.10		.17		.25		.37
59+40	101.05	60+30	101.12	61+20	101.19	62+10	101.24	63+00	101.36
	.05		.10		.19		.27		
	.06		.14		.20		.27		
	.06		.17		.18		.26		
	.07		.13		.18		.27		
59+50	101.07	60+40	101.11	61+30	101.17	62+20	101.27		
	.08		.10		.19		.26		
	.08		.14		.18		.28		
	.08		.13		.16		.27		
	.08		.15		.21		.24		
59+60	101.08	60+50	101.13	61+40	101.22	62+30	101.30		
	.08		.12		.19		.29		
	.08		.14		.14		.29		
	.08		.12		.21		.29		
	.08		.10		.24		.29		

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UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
Air Force Weapons Laboratory (WLCT)
Kirtland Air Force Base, New Mexico 87117

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP

3. REPORT TITLE
C-141A GROUND FLOTATION TEST ON LANDING MAT AND UNSURFACED RUNWAYS--CIVIL ENGINEERING SUPPORT

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
December 1967-September 1968

5. AUTHOR(S) (First name, middle initial, last name)
DeLynn R. Hay, Capt, USAF

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
May 1970	80	9

8a. CONTRACT OR GRANT NO.

b. PROJECT NO. 476L

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
AFWL-TR-70-30

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of AFWL (WLCT), KAFB, NM, 87117. Distribution limited because of technology.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
AFWL (WLCT)
Kirtland AFB, NM 87117

13. ABSTRACT

(Distribution Limitation Statement No. 2)
The Air Force Weapons Laboratory, Civil Engineering Division (AFWL/WLCT), provided civil engineering support for the C-141A Ground Flotation Test on a landing mat runway and an unsurfaced runway. The flight tests were conducted by the Lockheed-Georgia Company. The primary objectives of the test program were to determine the capability of the C-141A aircraft to operate from landing mat runways and to demonstrate the capability to operate on an unsurfaced runway. The support provided included soil strength measurements on the runways, elevation profiles on the runways, and evaluation of the effect of the C-141A on the unsurfaced and landing mat runways. The data collected during the test program are presented and discussed. Approximately 370 takeoffs, landings, and taxis were conducted on the landing mat runway without any major operational problems. Fourteen C-141A operations were successfully conducted on an unsurfaced runway with soil strengths ranging from CBR 2 to CBR 20.

DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Flight tests C-141A aircraft Landing mat runway Unsurfaced runway						